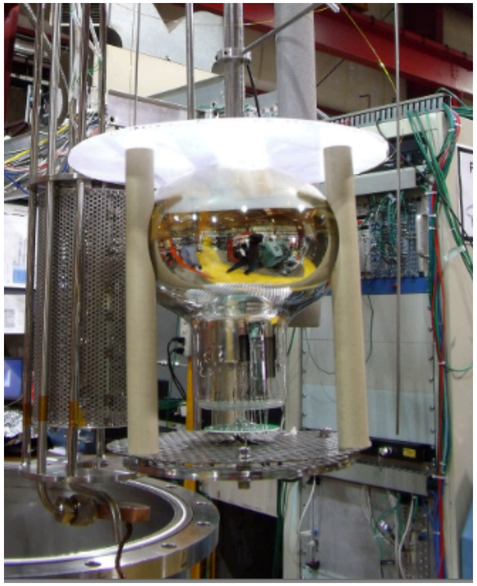
SCINTILLATION LIGHT DETECTION

IN

LARGE LIQUID ARGON TPCS

Ben Jones,

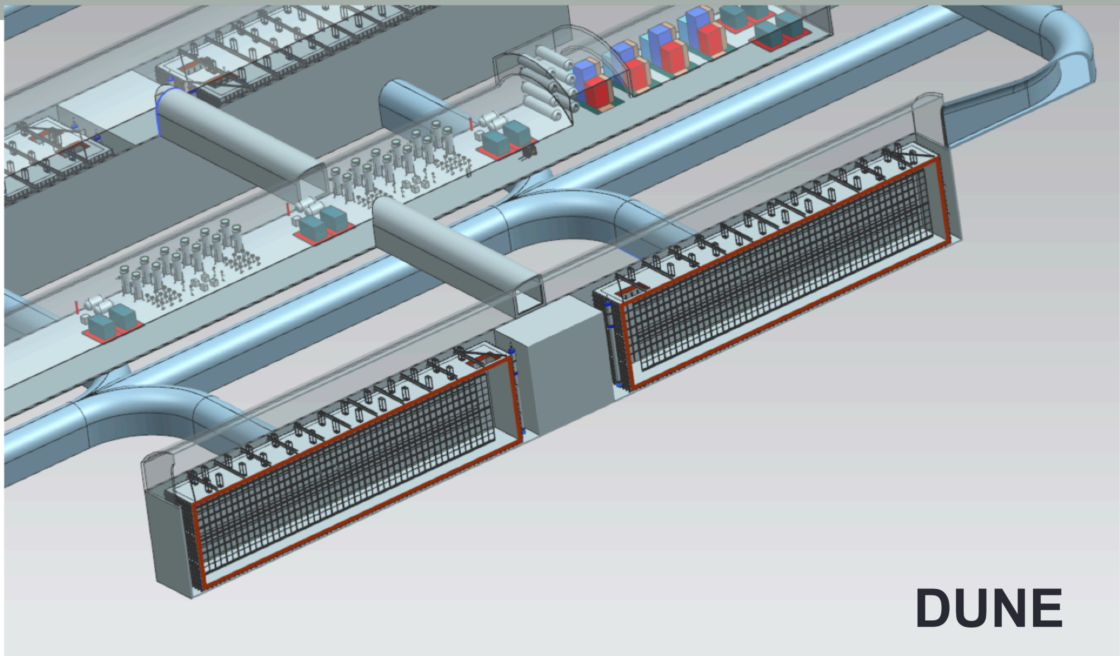
University of Texas at Arlington

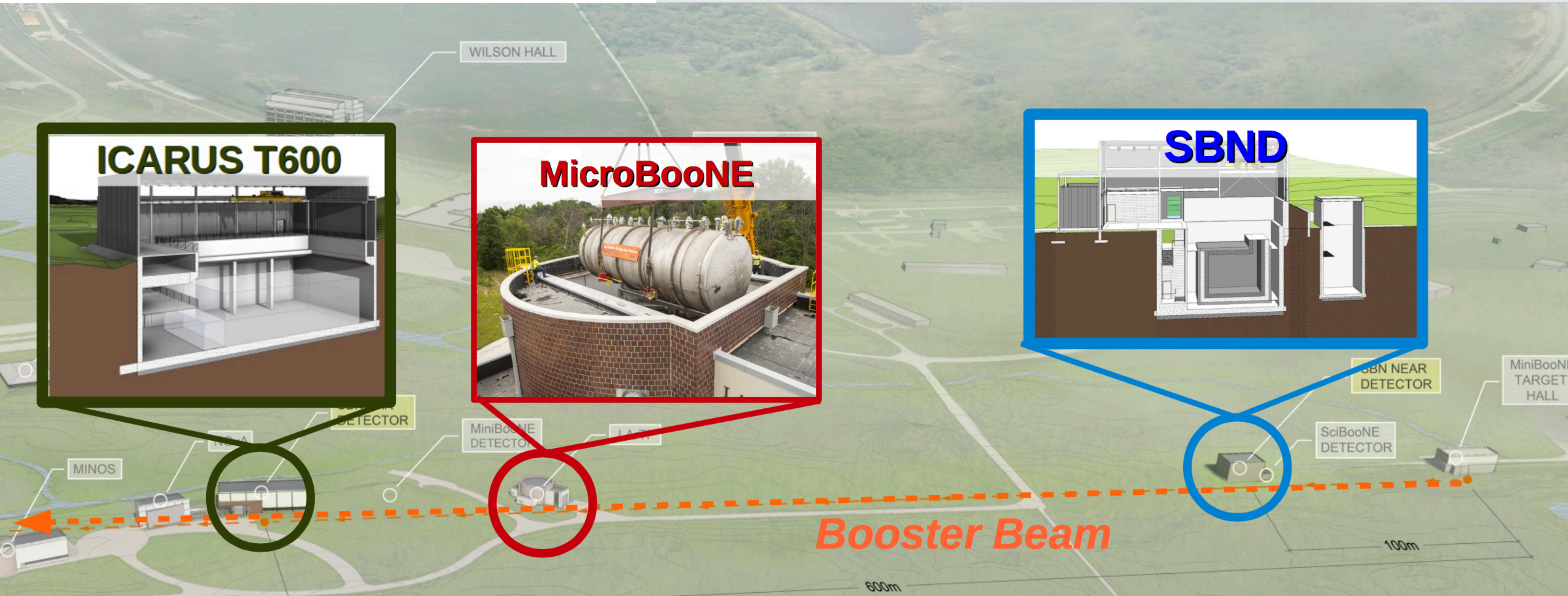


UNIVERSITY OF TEXAS ARLINGTON

Masschusetts Institute of Technology

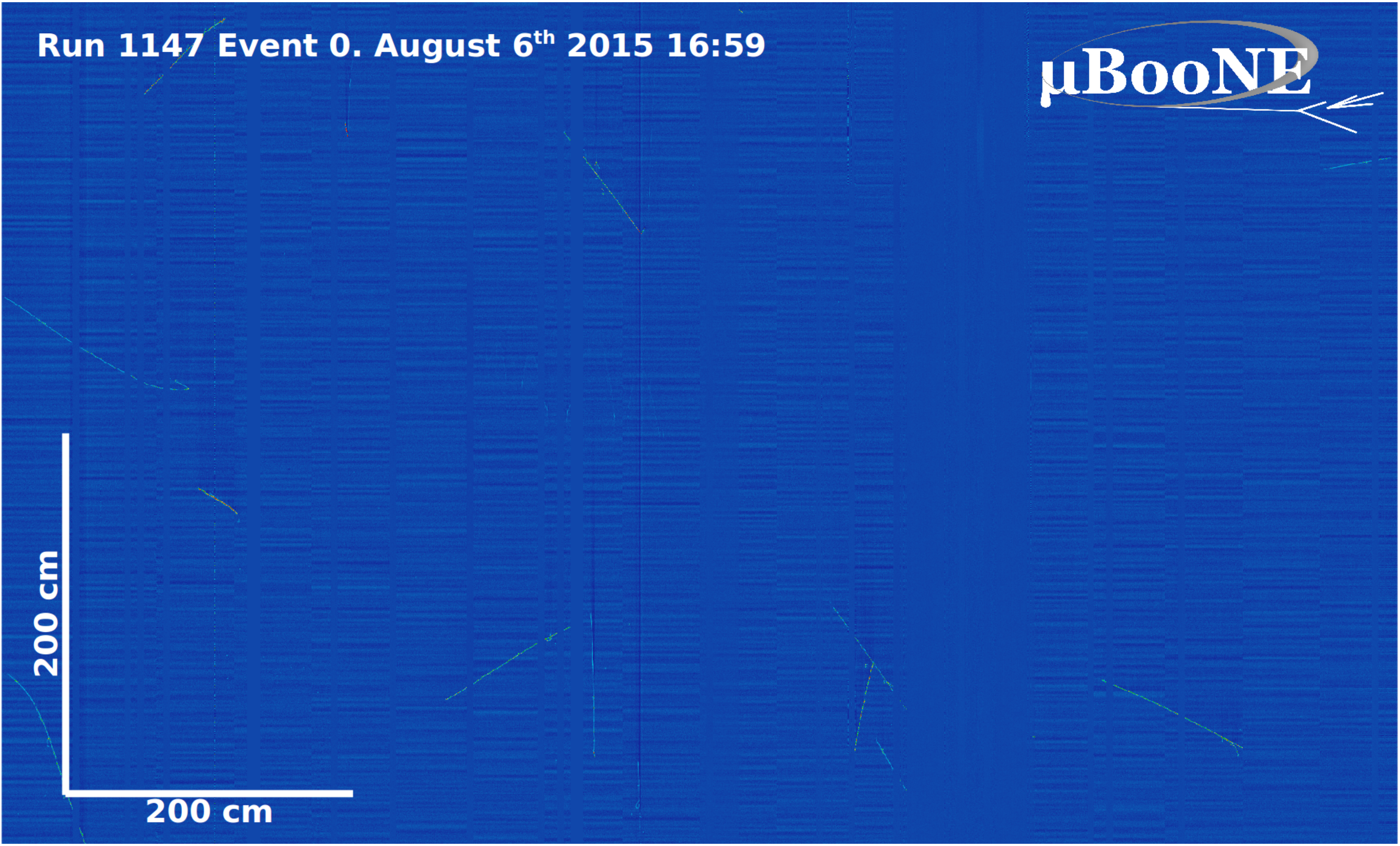
Large liquid argon TPCs are central to the US neutrino physics program





MicroBooNE Event Zero:

(half design field)



MicroBooNE Event Zero:

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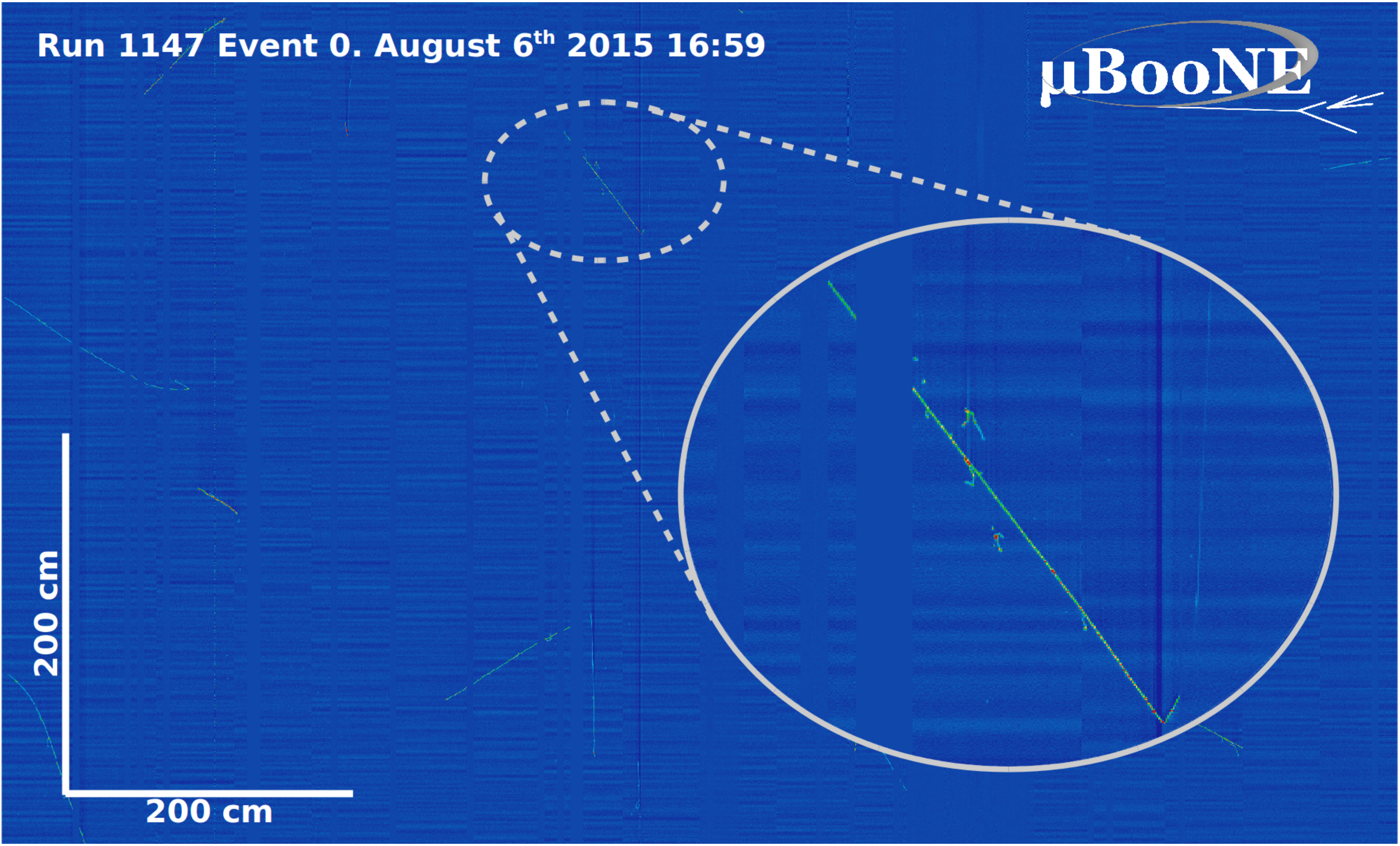

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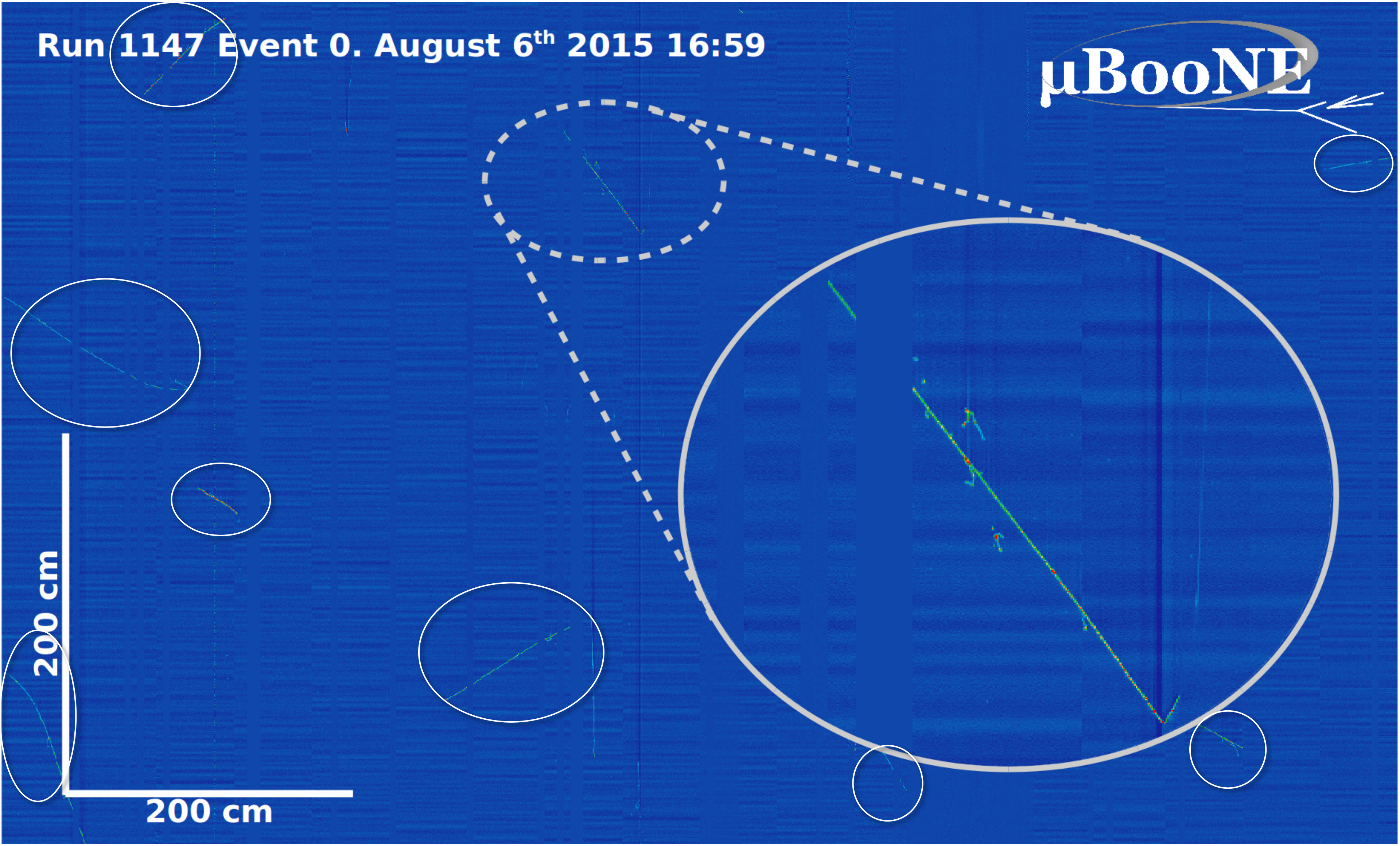
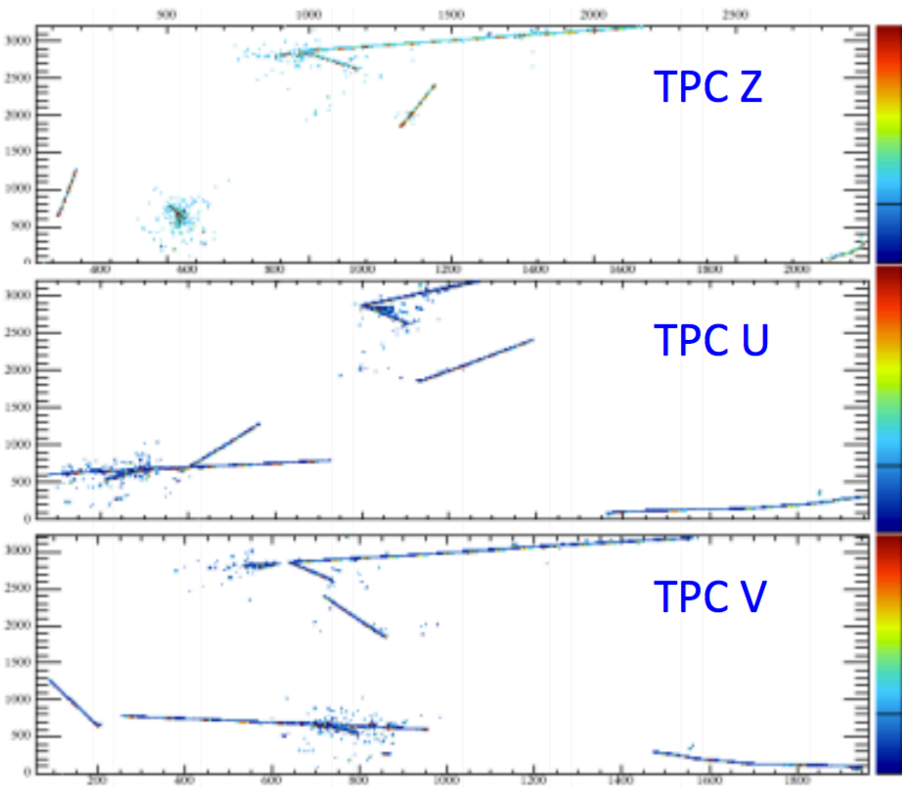
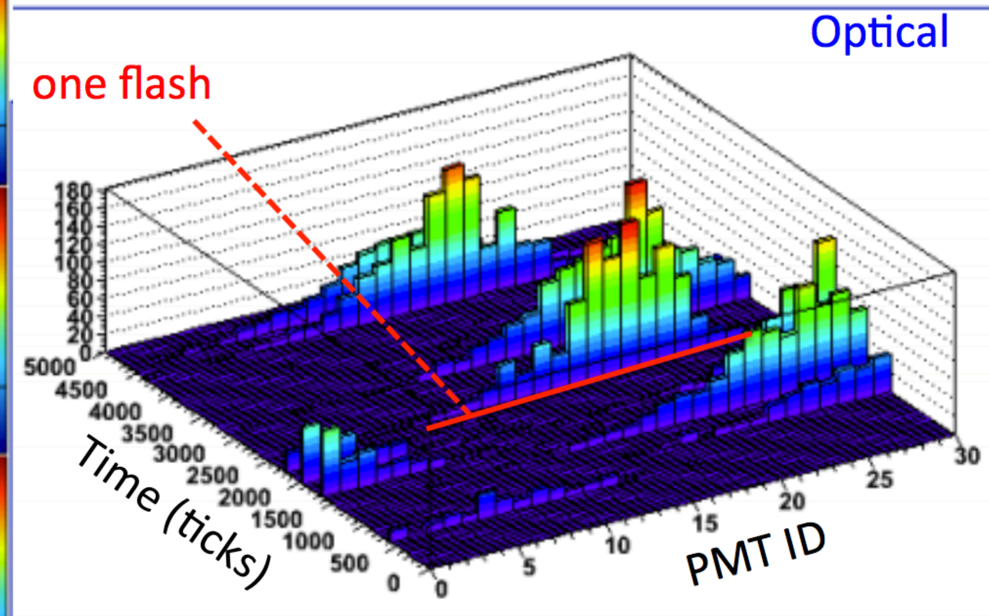
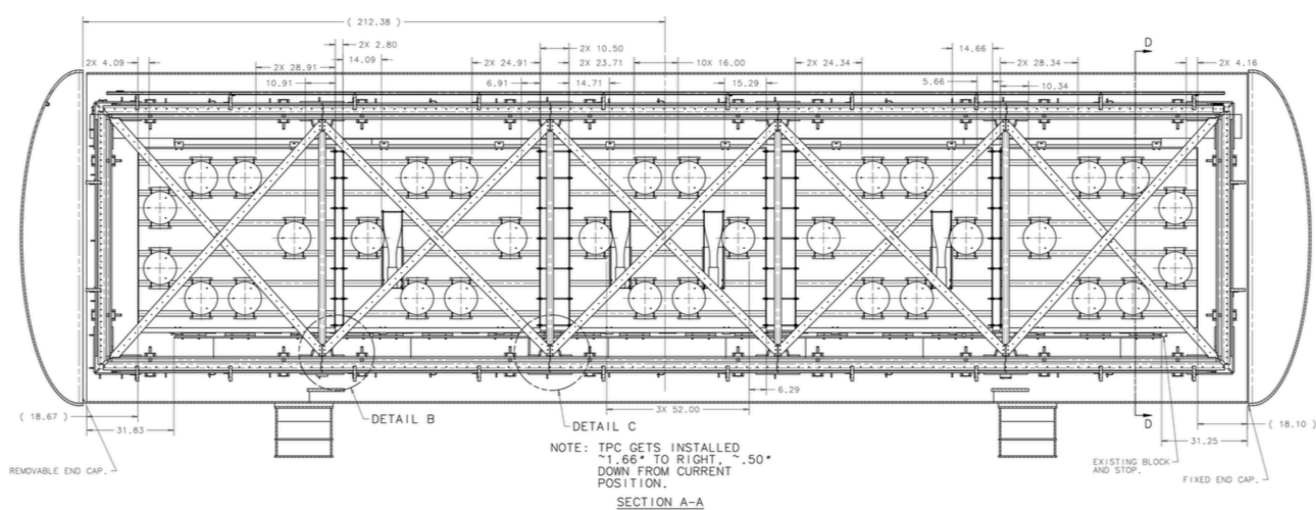
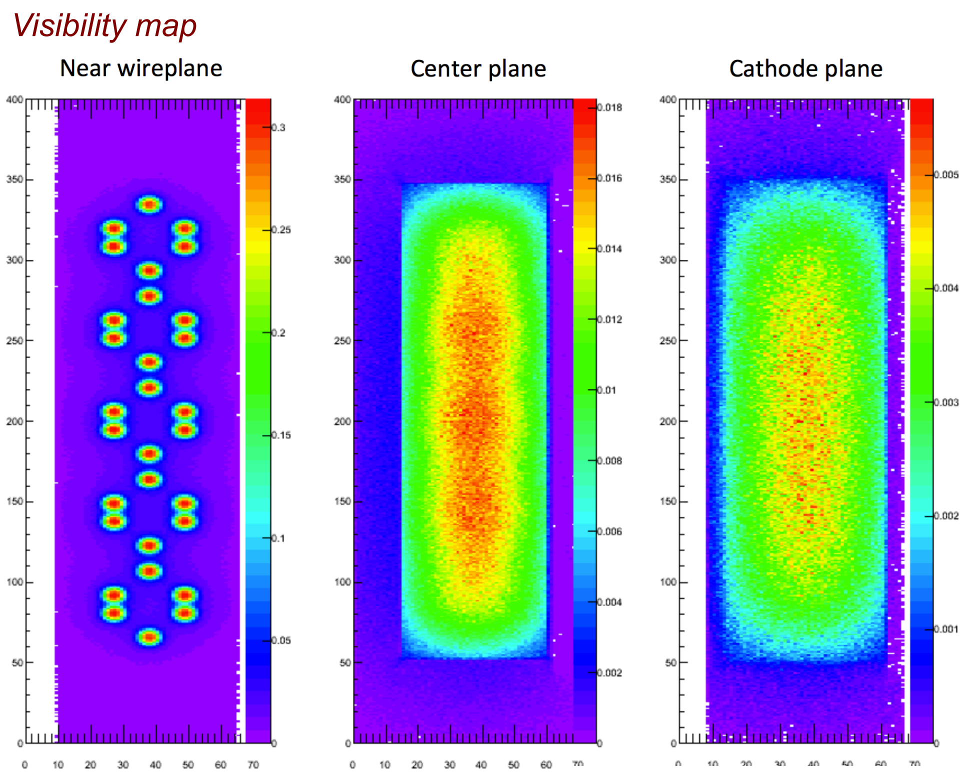






MicroBooNE simulations

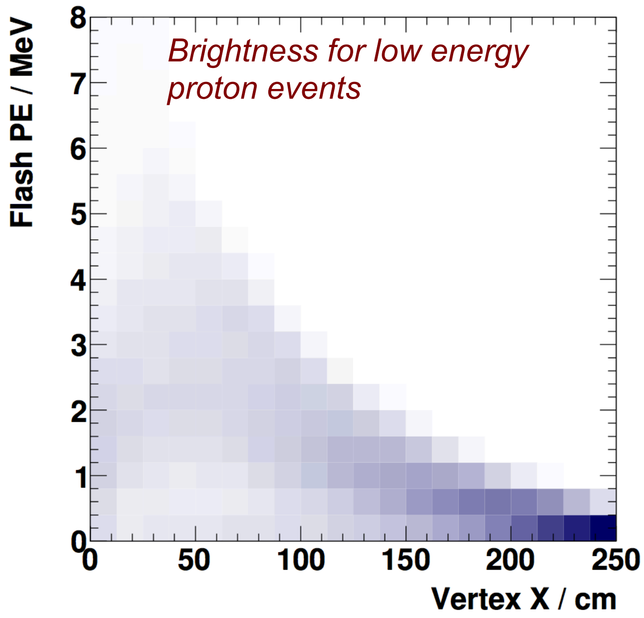


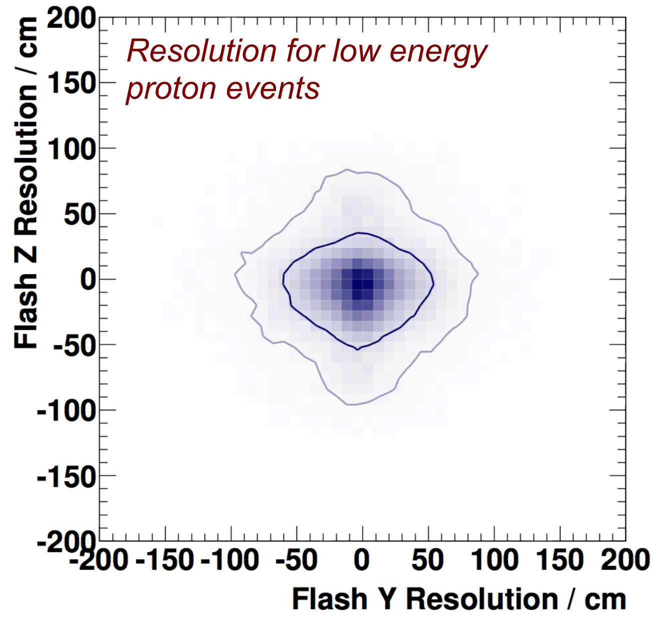


Simulated µBooNE performance

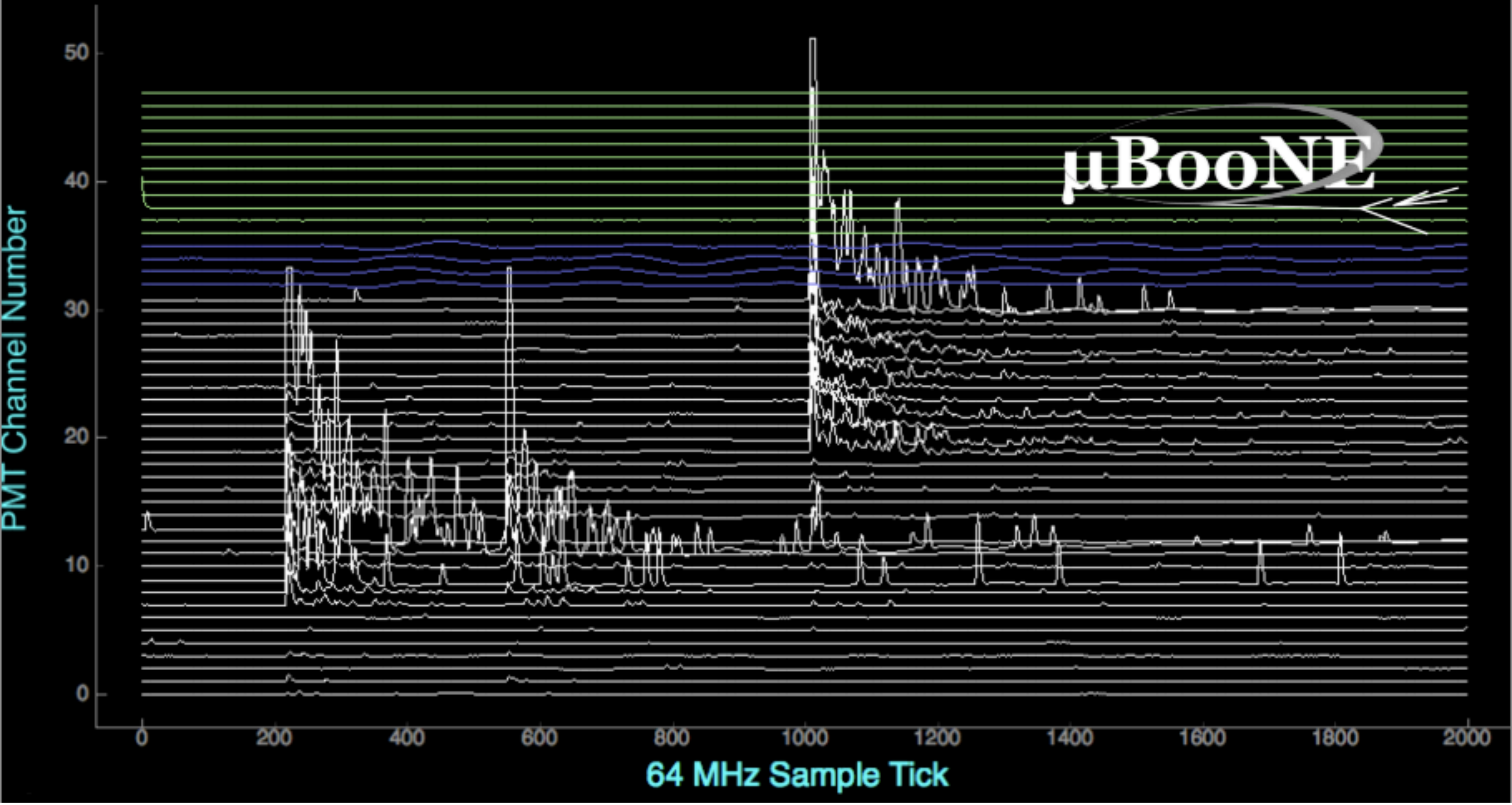
Plots from
FERMILAB-THESIS-2015-17

Expect verification with experimental data soon!





Real MicroBooNE PMT data



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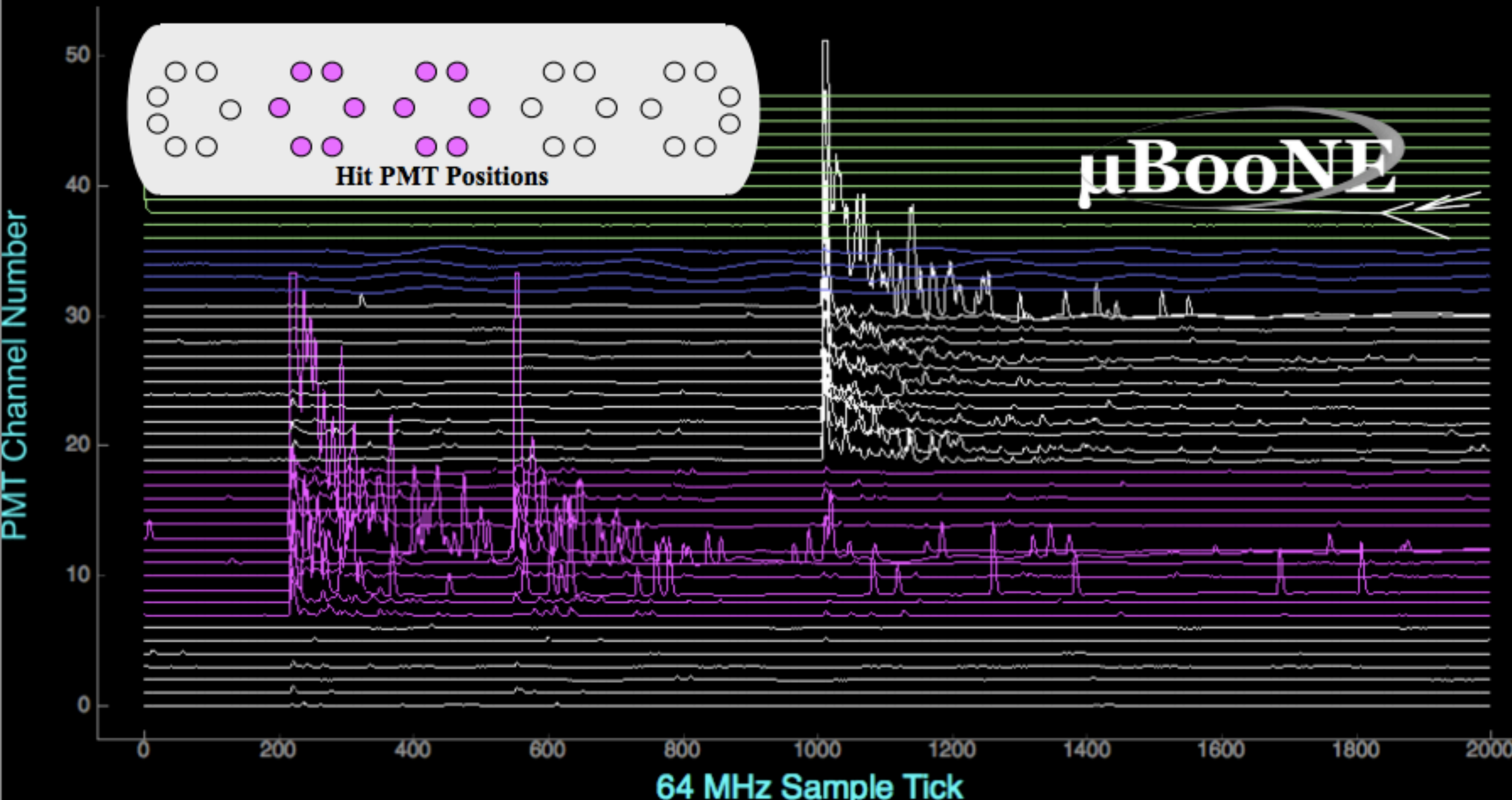

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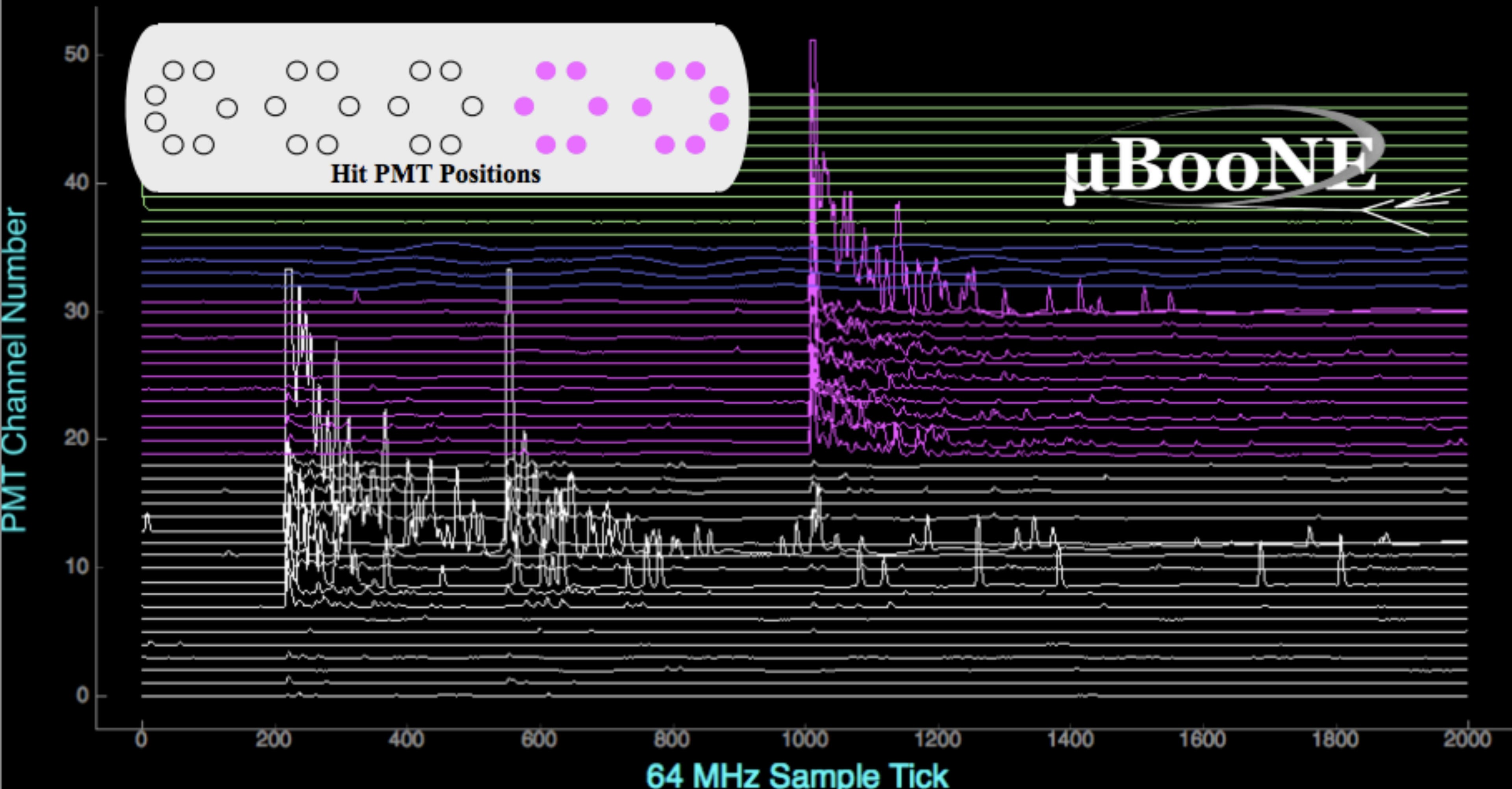
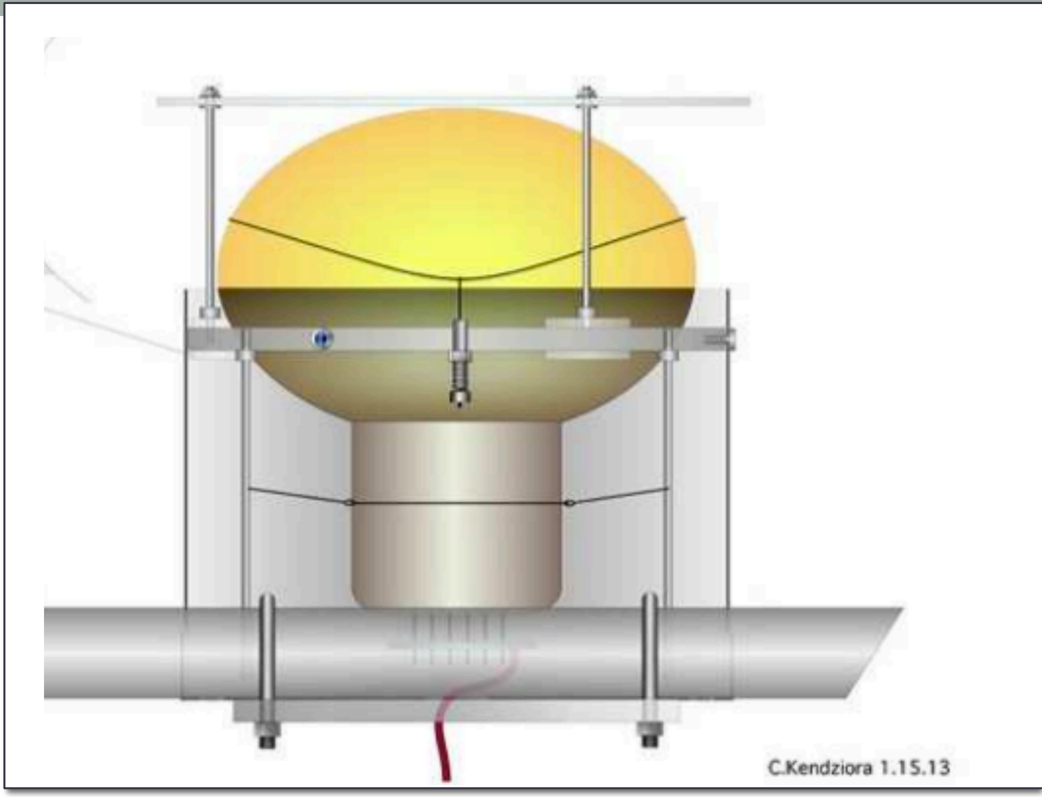
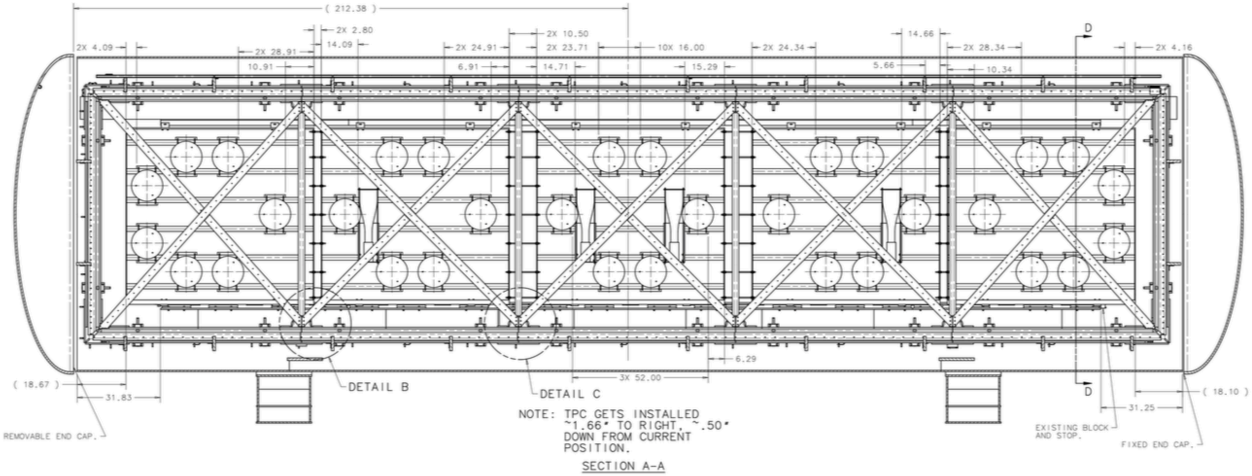
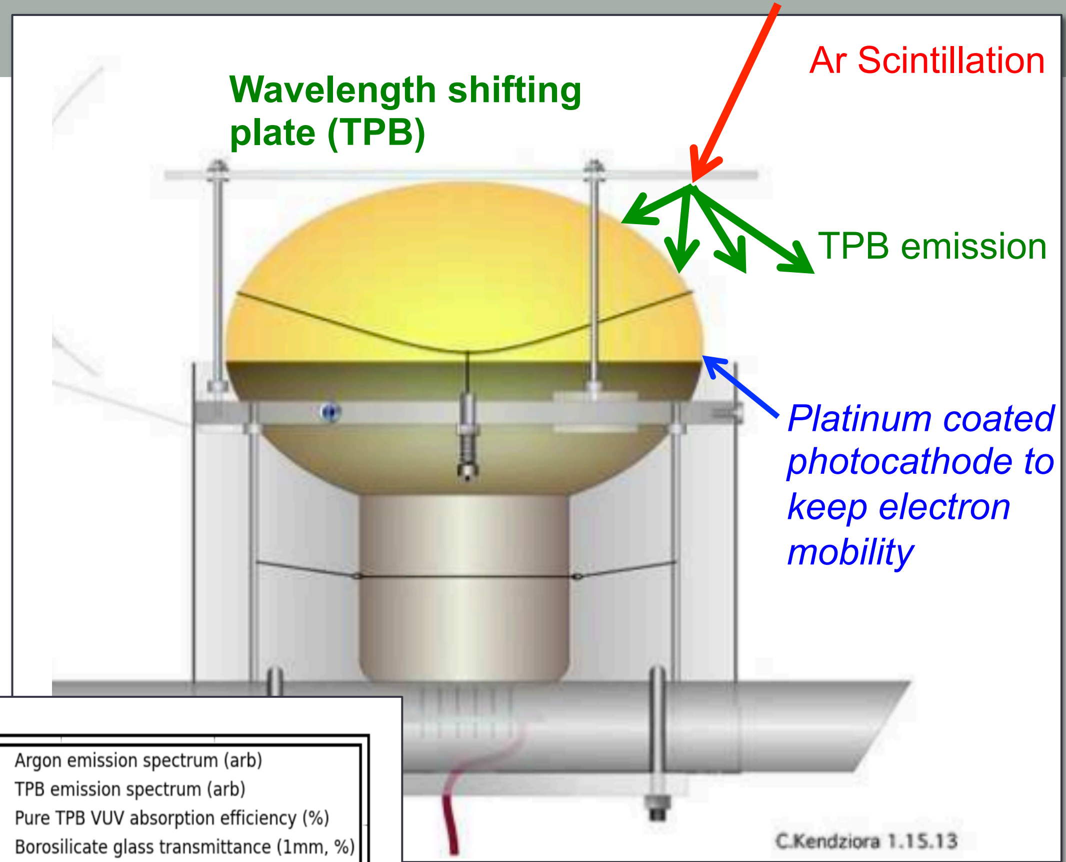


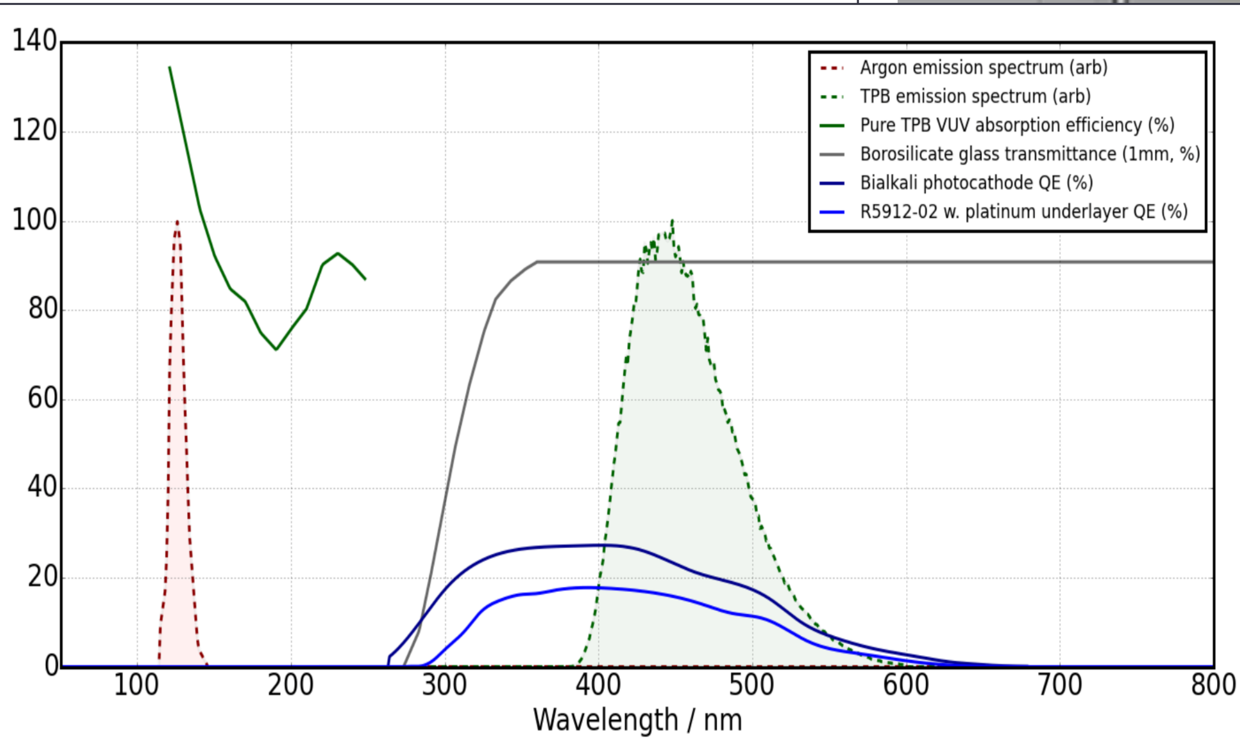
MicroBooNE system





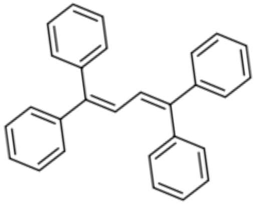


Ar Scintillation
Wavelength shifting plate (TPB)
TPB emission
Platinum coated photocathode to keep electron mobility
C.Kendziora 1.15.13

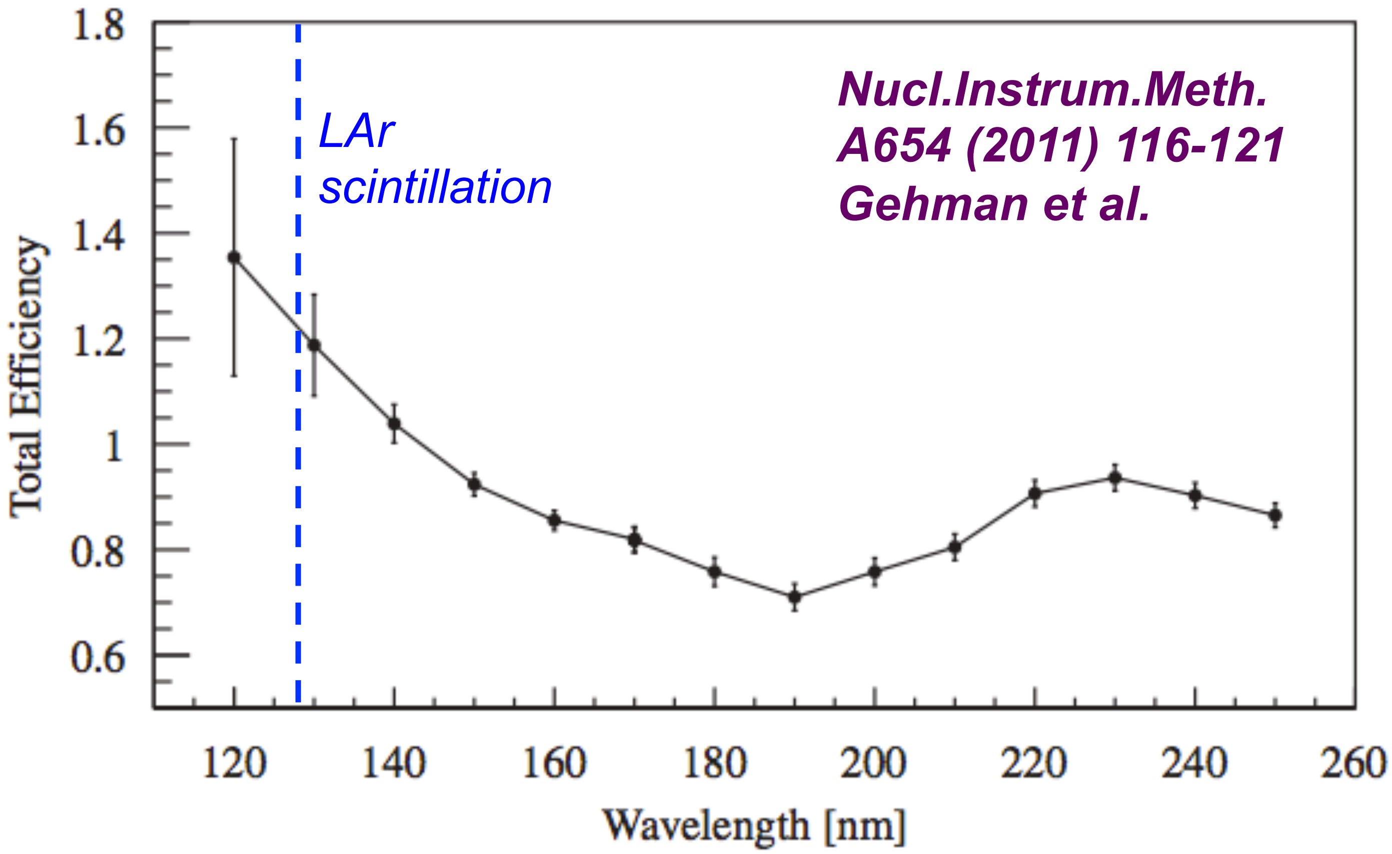


Argon emission spectrum (arb)
TPB emission spectrum (arb)
Pure TPB VUV absorption efficiency (%)
Borosilicate glass transmittance (1mm, %)
Bialkali photocathode QE (%)
R5912-02 w. platinum underlayer QE (%)
0
20
40
60
80
100
120
140
100
200
300
400
500
600
700
800
Wavelength / nm

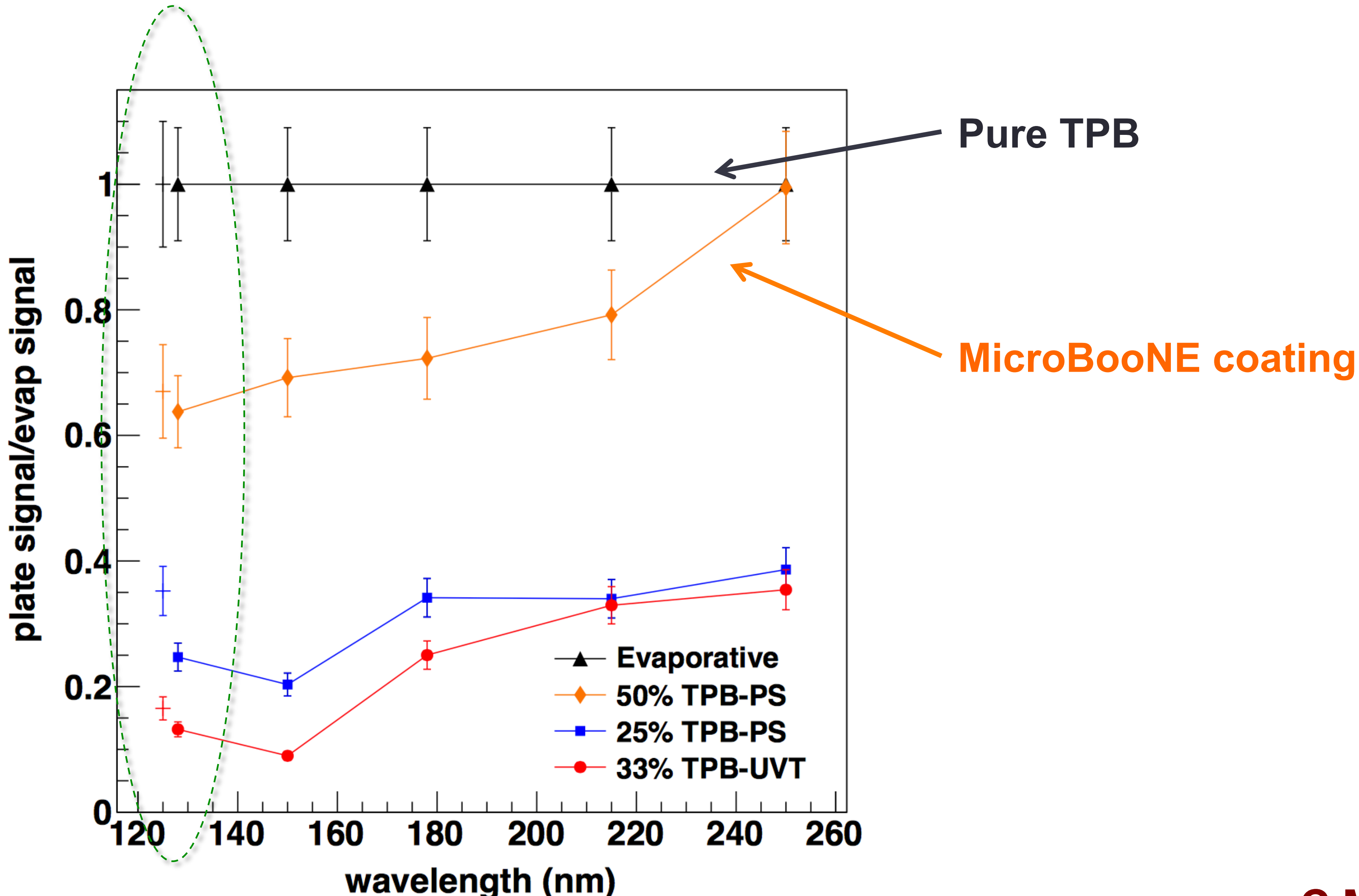
TPB Efficiency



- WLS efficiency of pure TPB has been quantified – at 128nm, about 1.2 visible photons out for 1 UV photon in.



TPB coating efficiency

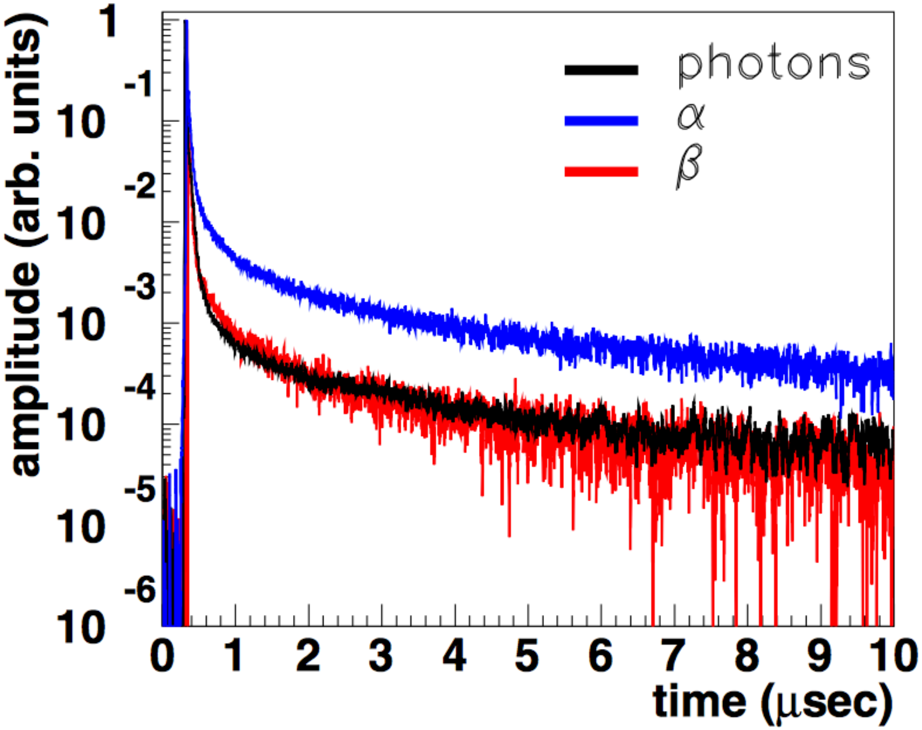


C.M. Ignarra
FERMILAB-THESIS-2014-31

TPB time response

E. Segreto
Phys. Rev. C 91, 035503

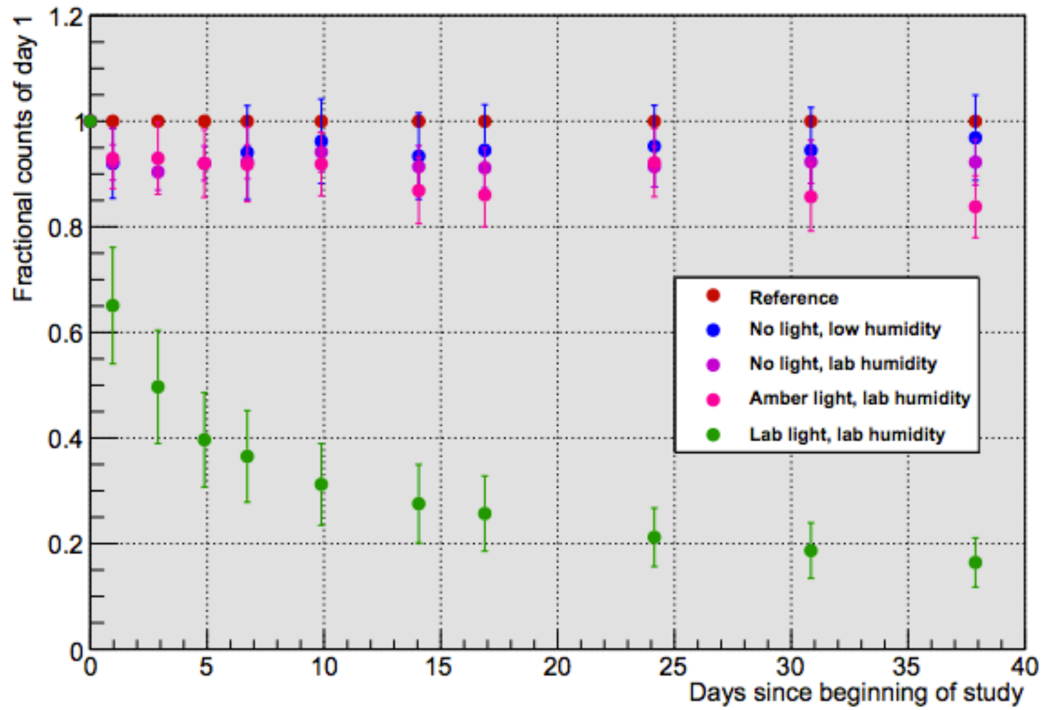
- A 250 nm and above, TPB response is prompt (1-2 ns)
- Recent work shows that at 128 nm, TPB has a long time tail
- Comparison with scintillation profiles gives possible interpretation:
- Scintillating secondary electron liberated from the molecule, exciting TPB triplets
- This also helps explain the 1.2 shifting efficiency

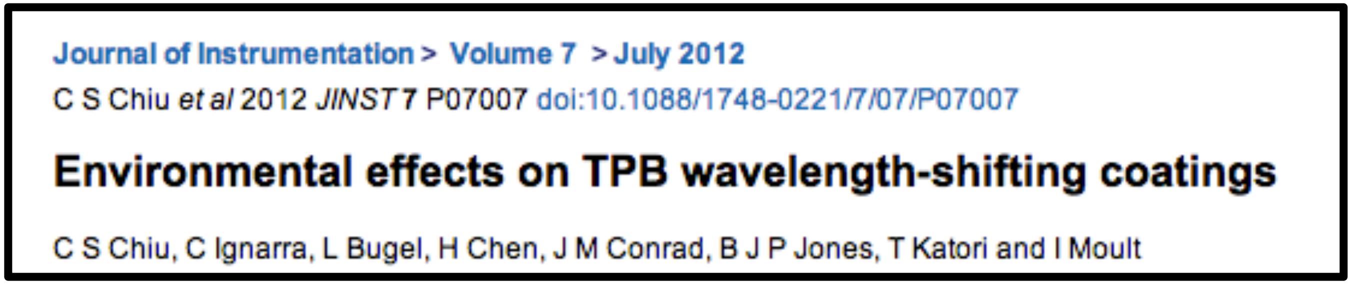


	Decay time (ns)	Abundance (%)
Instantaneous component	1–10	60 ± 1
Intermediate component	49 ± 1	30 ± 1
Long component	3550 ± 500	8 ± 1
Spurious component	309 ± 10	2 ± 1

Environmental sensitivity of TPB

- We found that TPB is very sensitive to UV light and degrades in performance
- Also yellows in color with exposure
- Components in modern LArTPCs must last 10s of years



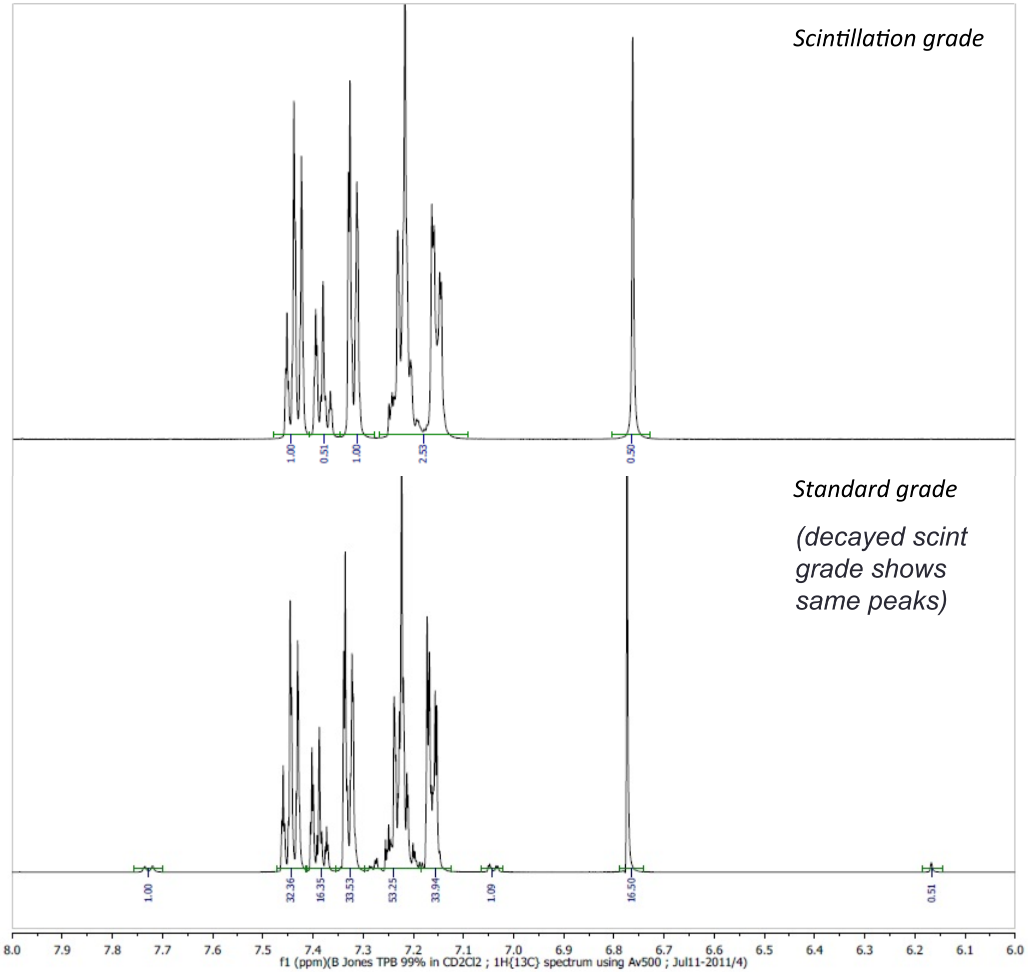


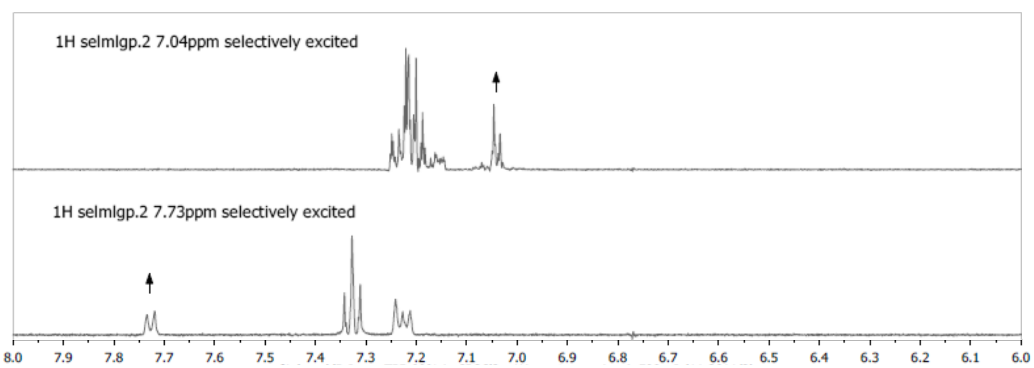
Journal of Instrumentation > Volume 7 > July 2012

C S Chiu *et al* 2012 *JINST* 7 P07007 doi:10.1088/1748-0221/7/07/P07007

Environmental effects on TPB wavelength-shifting coatings

C S Chiu, C Ignarra, L Bugel, H Chen, J M Conrad, B J P Jones, T Katori and I Moult



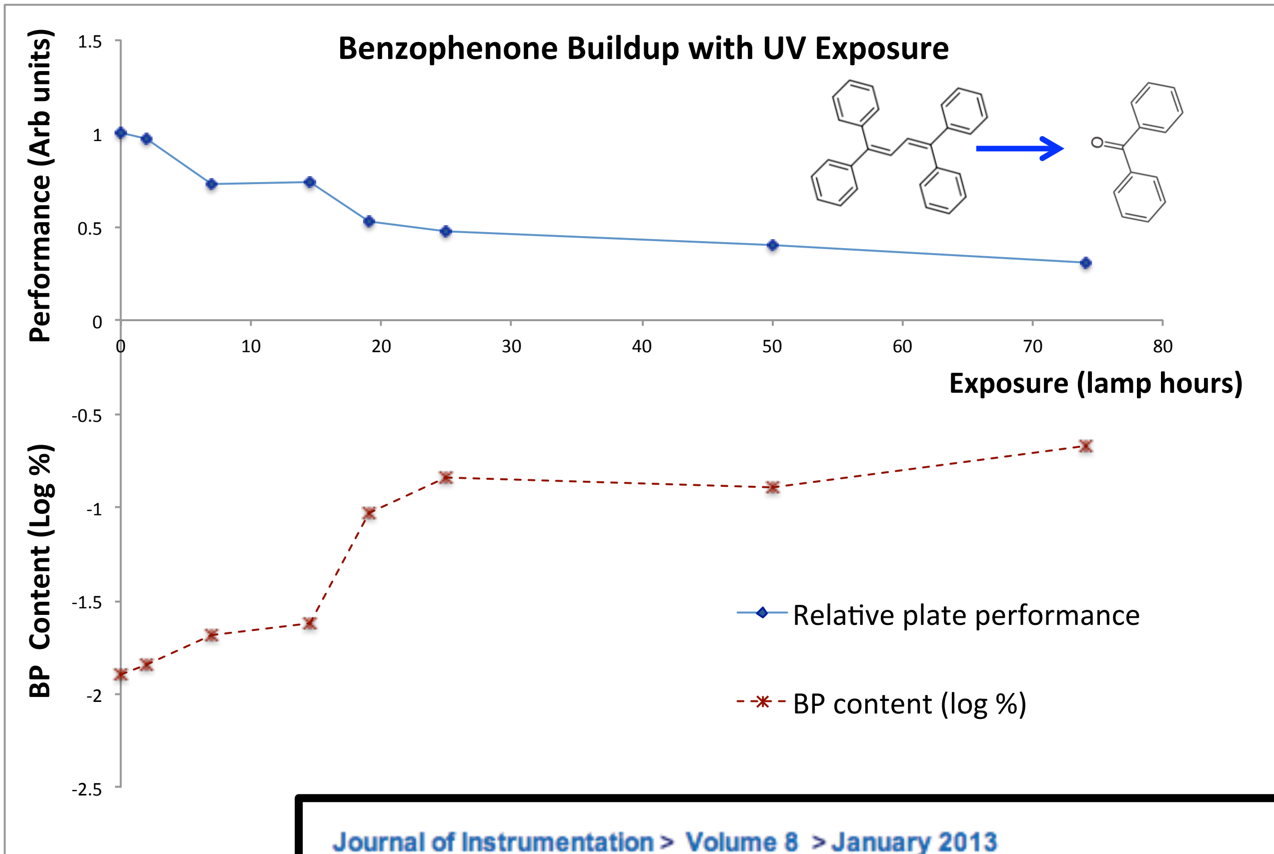


Photodegradation Mechanism of TPB

NMR investigations show spontaneously evolved photo-initiating impurities in TPB

The impurity is present at low level in lower commercially available grades of TPB

Monitoring decay with GCMS



Working with GCMS we identified the degradation mechanism – radical mediated photo-oxidation to benzophenone

Demonstrated delayed degradation using radical mediators confirms this interpretation

Oxygen is required. Submerged in LAr, should be safe from decay.

More on this later…

Journal of Instrumentation > Volume 8 > January 2013

B J P Jones *et al* 2013 *JINST* **8** P01013 doi:10.1088/1748-0221/8/01/P01013

Photodegradation mechanisms of tetraphenyl butadiene coatings for liquid argon detectors

B J P Jones[a], J K VanGemert[b], J M Conrad[a] and A Pla-Dalmau[b]

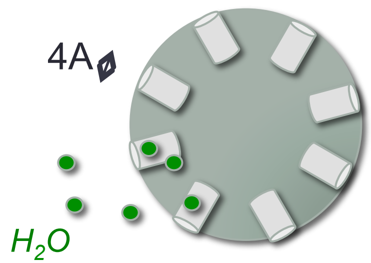
Bo Vertical Slice Test Stand

- Test bed for the MicroBooNE optical system including:
  - *Cryogenic photomultiplier tubes*
  - *Base electronics*
  - *Wavelength shifting plate*
  - *High voltage system + interlocks*
  - *Cables and splitters*
  - *Readout electronics*
  - *Cryostat feedthrough*
  - *Trace impurity monitors*
  - *Etc…*

Also used for liquid argon R&D work for MicroBooNE, DUNE, etc

Removing H_2O and O_2

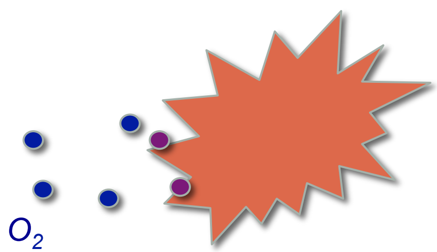
- ***Water*** removed by 4A molecular sieves



Very large effective surface area for molecules with d < 4A

water d ~ 2.75 A

- ***Oxygen*** removed by activated copper granules



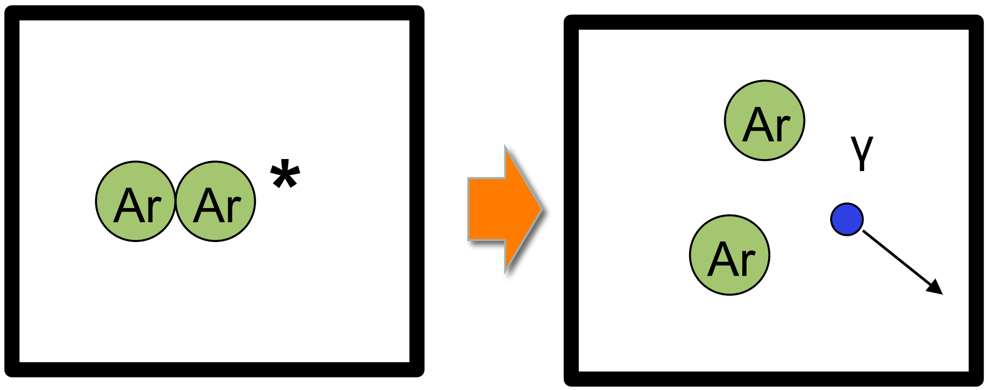
Oxygen trapped by oxidizing the copper

$$Cu + \tfrac{1}{2}O_2 \rightarrow CuO$$

- 10 ppt levels of water and oxygen impurity can be achieved

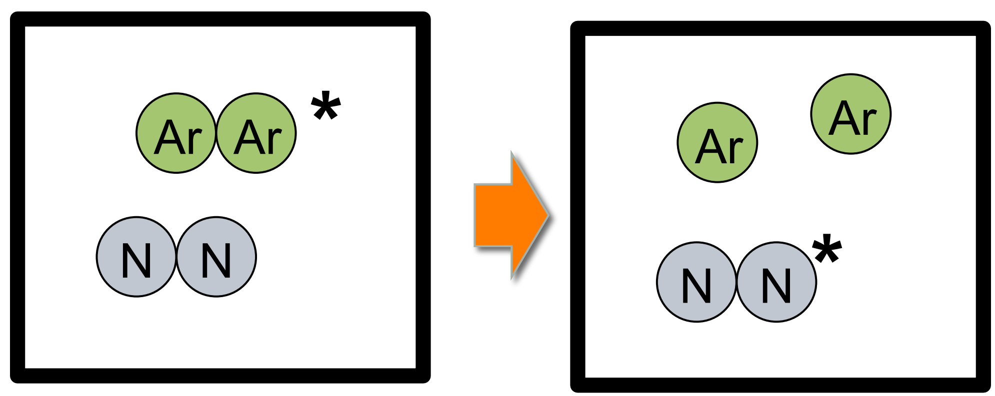
Nucl.Instrum.Meth 605A 3 306-311

Effect of Nitrogen : 1. Quenching



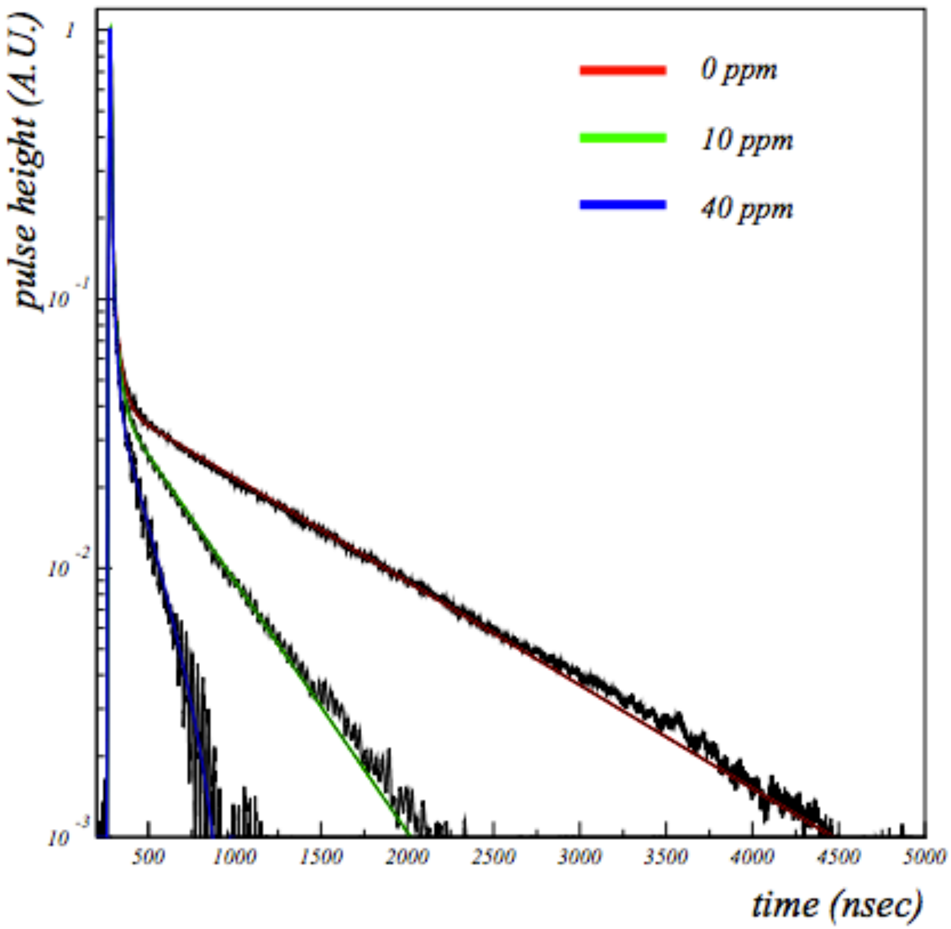
Scintillation process

Competing Excimer Dissociation Process



Rate dependent on the density of excimers and density of impurity

Quenching due to Nitrogen



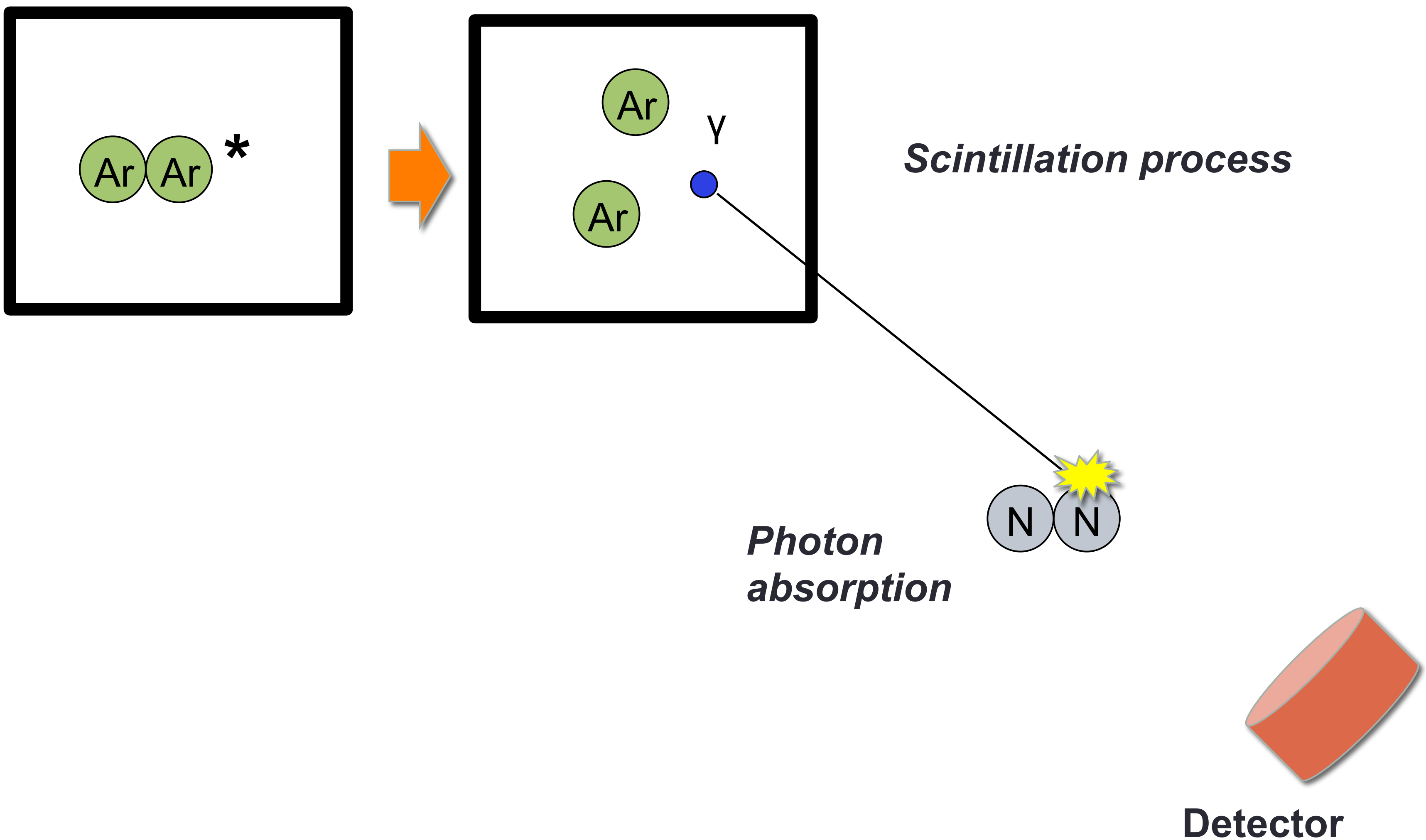
Much stronger effect on triplet state – longer time for collisions to occur

Affects time constant as well as total light yield and fast / slow ratio

Systematic study shows that nitrogen should be kept < 2 ppm to prevent significant quenching

2010 JINST 5 P06003
WArP collaboration

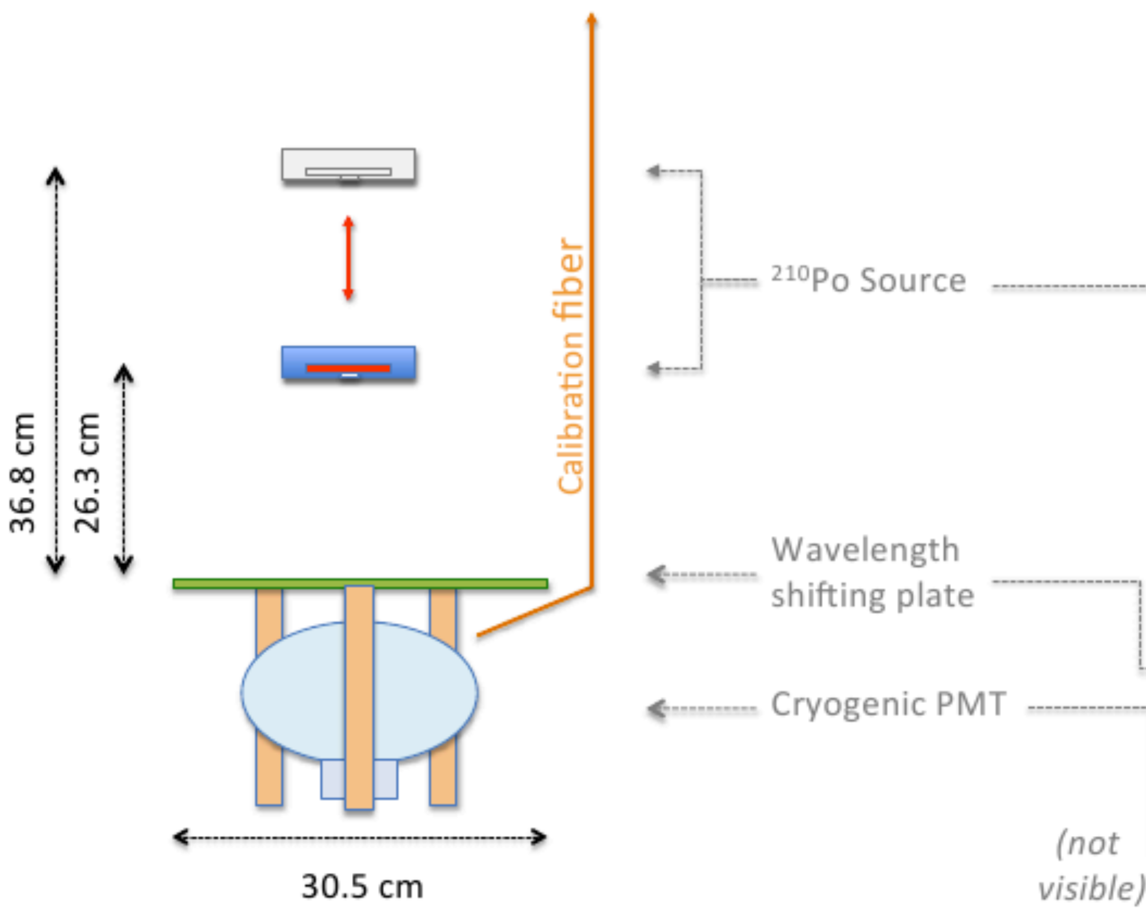
Effect of Nitrogen: 2. Absorption



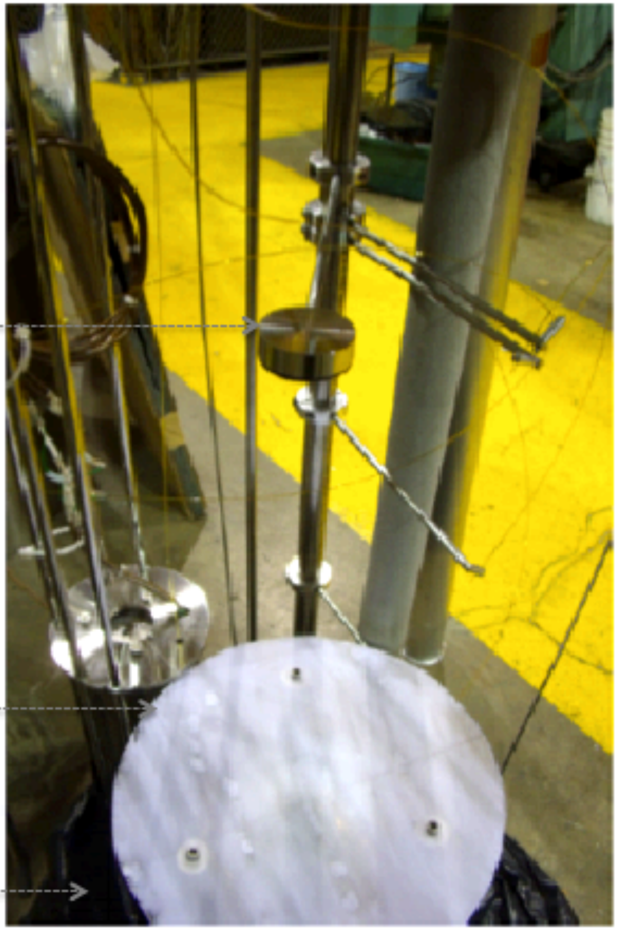
A measurement of the absorption of liquid argon scintillation light by dissolved nitrogen at the part-per-million level

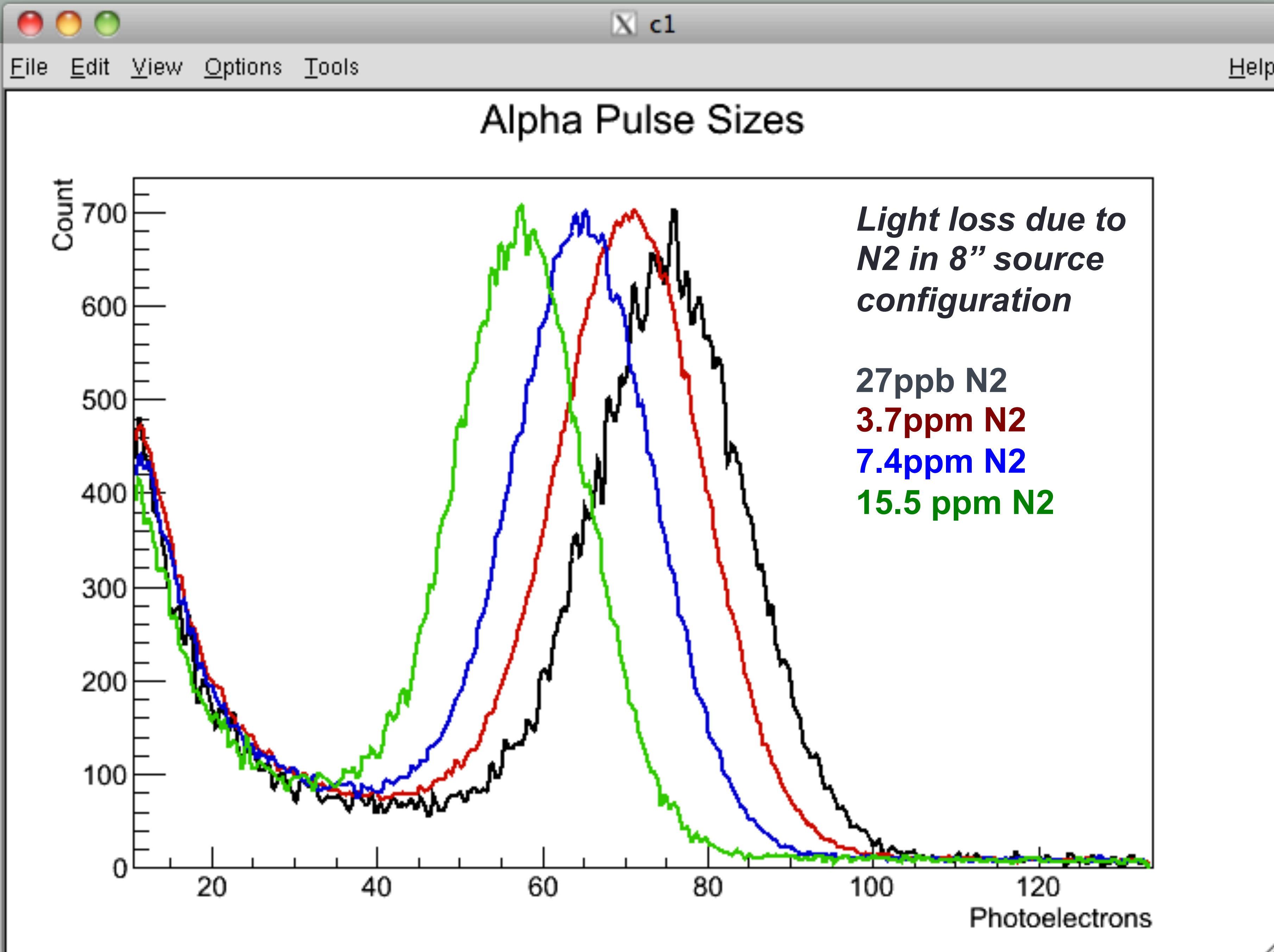
B J P Jones, C S Chiu, J M Conrad, C M Ignarra, T Katori and M Toups

Published 24 July 2013 • © 2013 IOP Publishing Ltd and Sissa Medialab srl • Journal of Instrumentation, Volume 8, July 2013



Top View





c1
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Alpha Pulse Sizes
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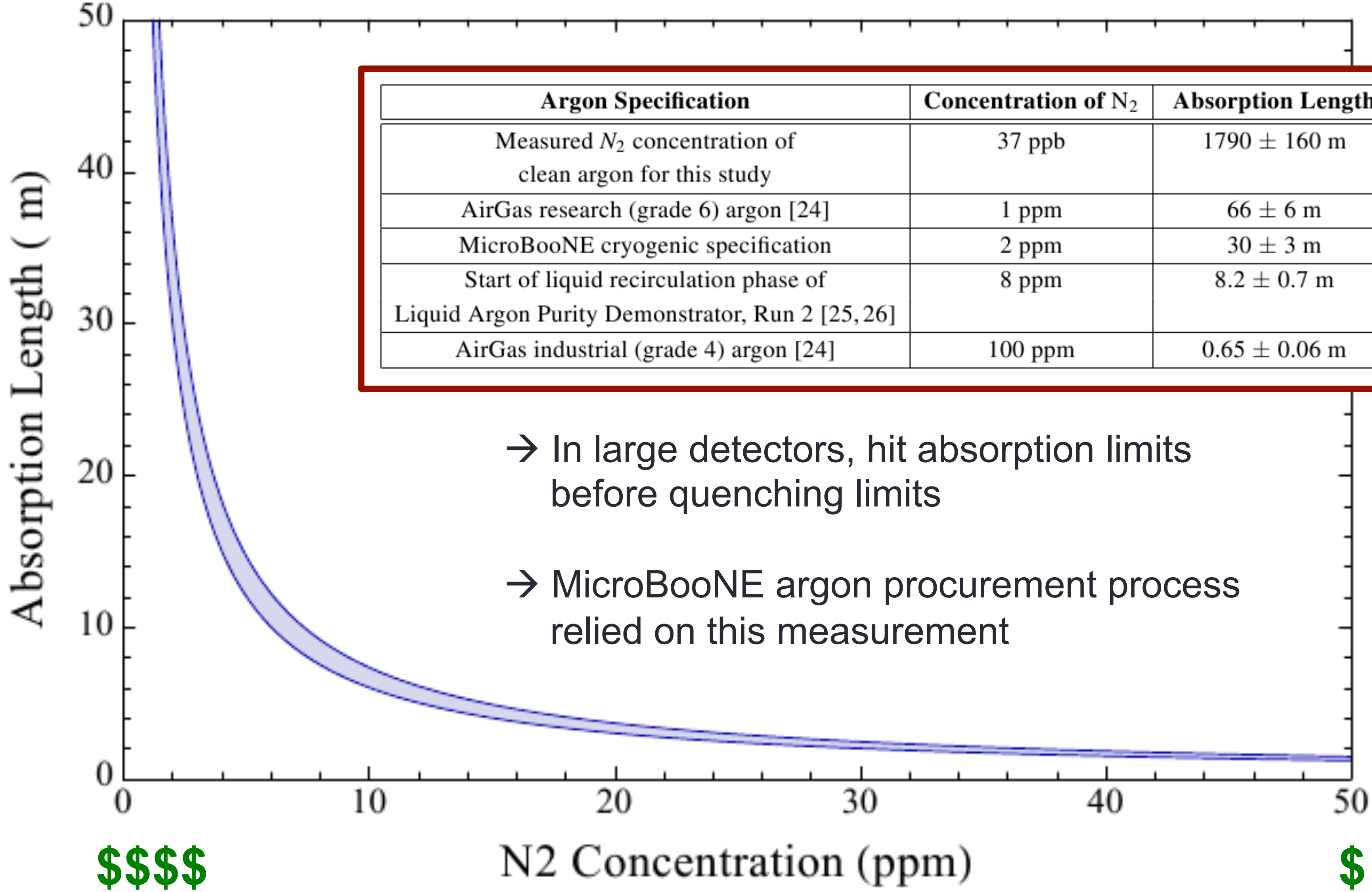
300
400
500
600
700
20
40
60
80
100
120
Photoelectrons
Light loss due to N2 in 8” source configuration
27ppb N2
3.7ppm N2
7.4ppm N2
15.5 ppm N2

Implications for LArTPC Detectors

Argon Specification	Concentration of N_2	Absorption Length
Measured N_2 concentration of clean argon for this study	37 ppb	1790 ± 160 m
AirGas research (grade 6) argon [24]	1 ppm	66 ± 6 m
MicroBooNE cryogenic specification	2 ppm	30 ± 3 m
Start of liquid recirculation phase of Liquid Argon Purity Demonstrator, Run 2 [25, 26]	8 ppm	8.2 ± 0.7 m
AirGas industrial (grade 4) argon [24]	100 ppm	0.65 ± 0.06 m

→ In large detectors, hit absorption limits before quenching limits

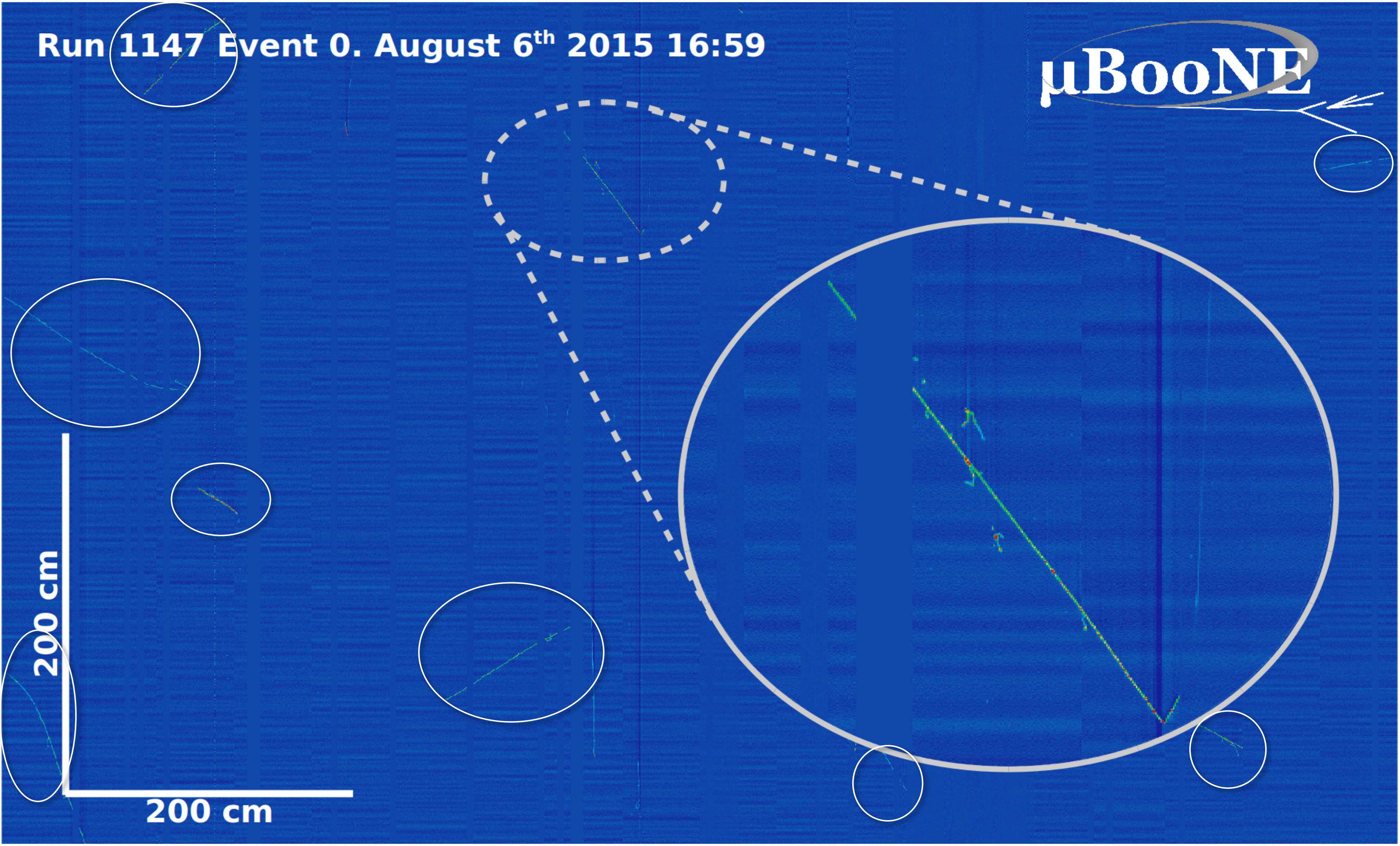
→ MicroBooNE argon procurement process relied on this measurement



What should drive the design? (my opinion…)

MicroBooNE Event Zero:

(half design field)



What should drive the design? (my opinion…)

- **Maximize spatial resolution.**

What should drive the design? (my opinion…)

- **Maximize spatial resolution.**

Within the constraints:

- Fixed $$

- Keep within detector real-estate

- Don't hurt the TPC system

By doing the following:

- More channels per $

- More light per channel

.

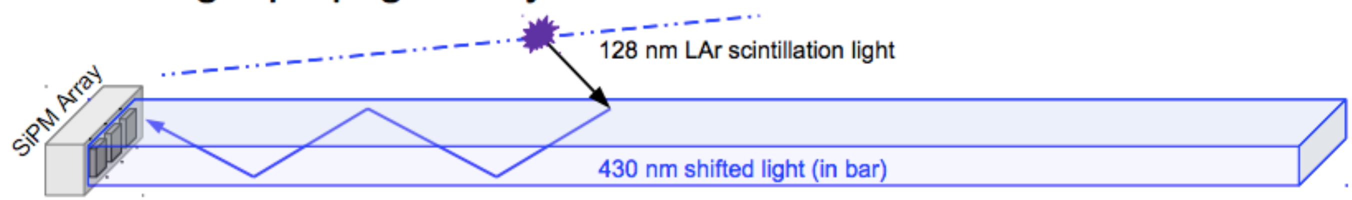
I am only going to highlight only the ideas that seem to achieve this.

More channels per $

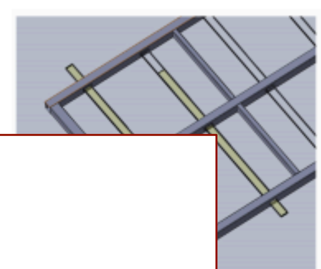
Denver Whittington – LIDINE2015 talk

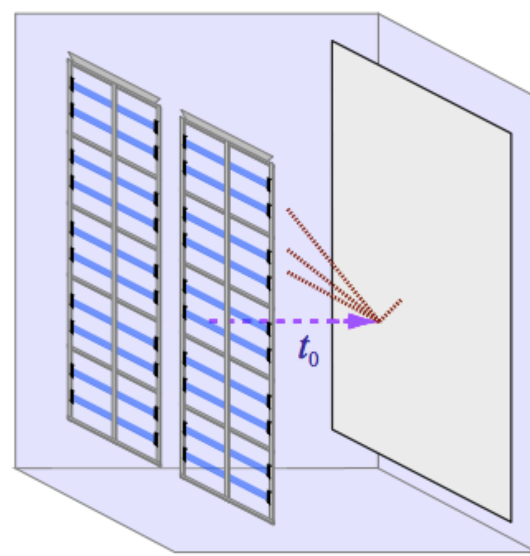
Light Guides for Large-Area Photon Detection

- Large active-area UV-collecting light guides
  - Acrylic or polystyrene imbued with wavelength-shifting compound
    - Based on design pioneered by MIT
    - Dip-coating w/ TPB in solvent (after studying many different methods)
  - 430 nm light propagated by total internal reflection to end



- Embed PD paddles inside anode plane assembly behind collection wires
  - Large photosensitive area with small photocathode area
  - Low-voltage SiPM bias
  - Easily scalable

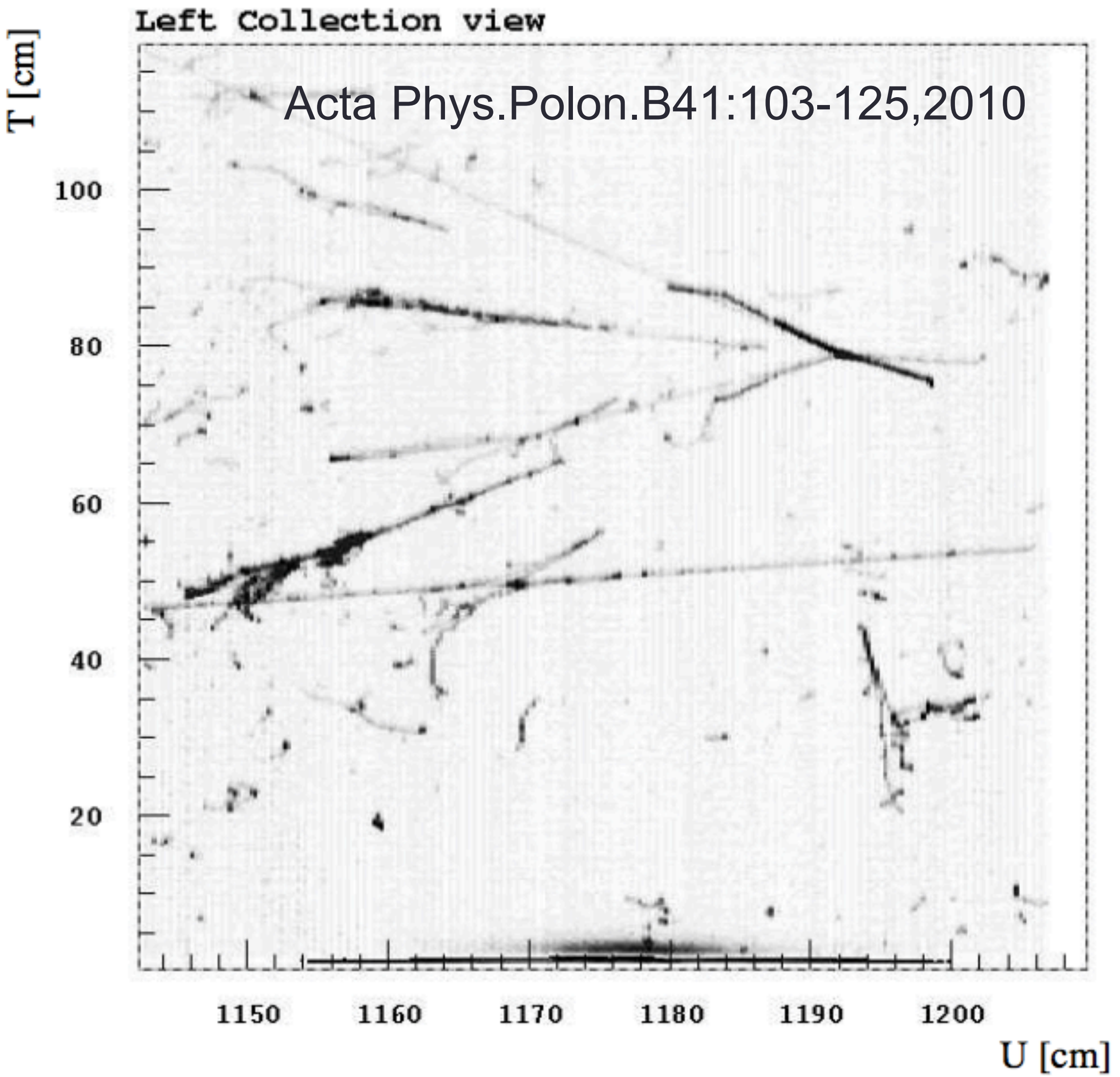




- PMTs → SiPMs drives unit cost down
- Removes HV requirement
- But mandates additional collectors (eg lightguides)

More channels per $:

This is an event from the ICARUS TPC:



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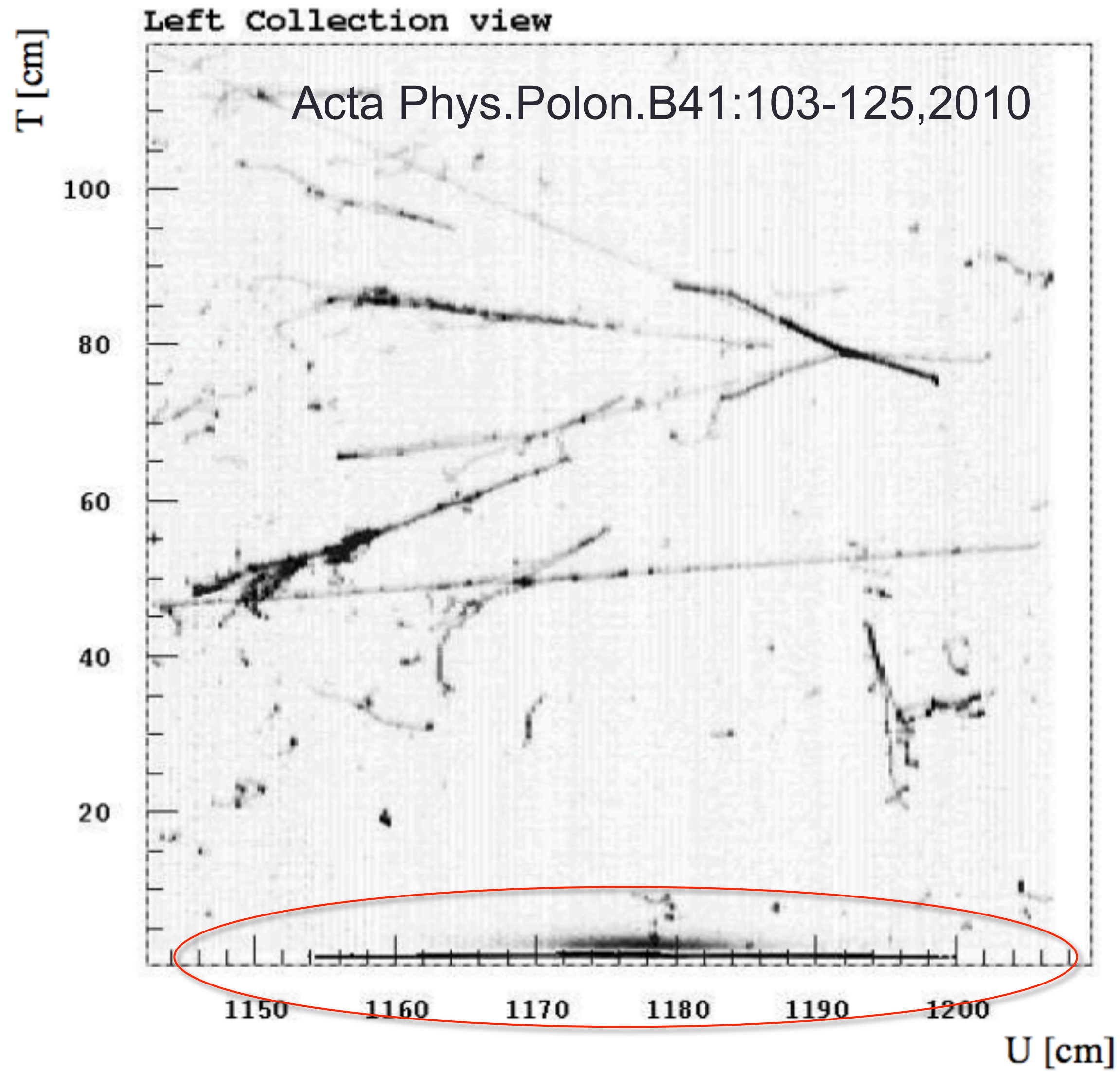
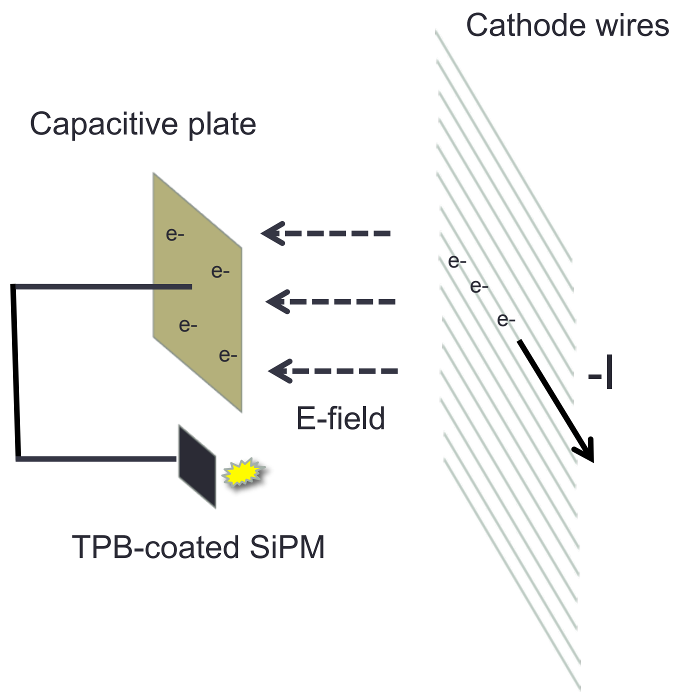


Crosstalk from the PMT system to the wire planes

Readout PMT system through crosstalk alone?

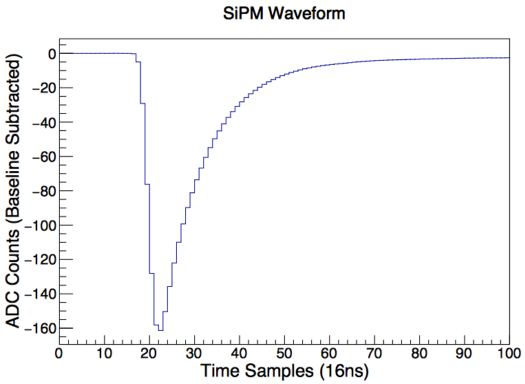
arxiv:1507.01997 Z. Moss et al

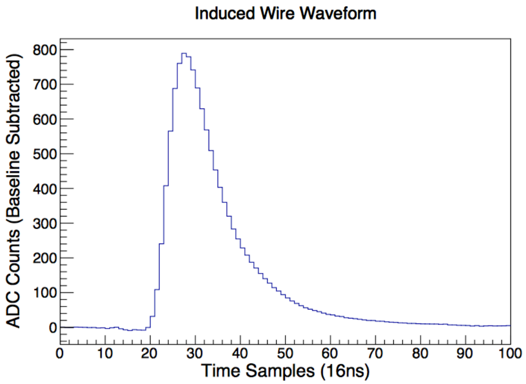


- Proposal to remove PMT readout electronics system altogether and purely read out via crosstalk

- Possibly boost crosstalk with an extra antenna to increase capacitance between systems

- No readout electronics means more $ for sensitive elements





Back to light guides:

Denver Whittington – LIDINE2015 talk

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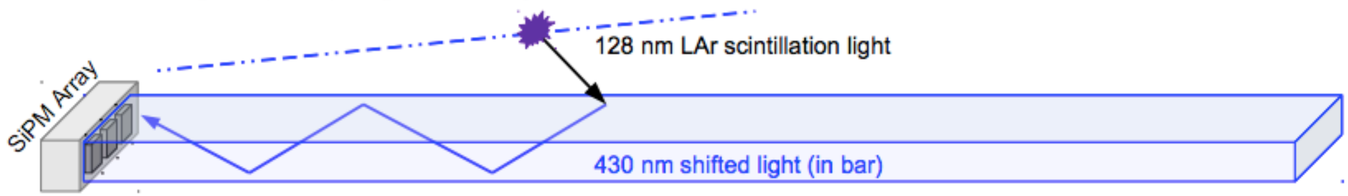

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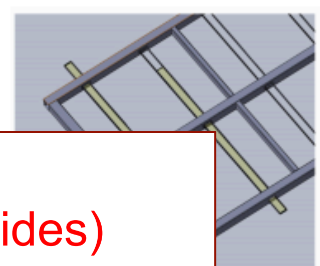
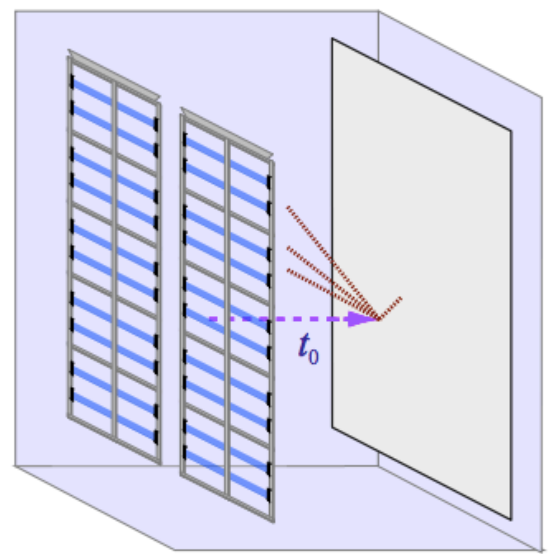




- PMTs → SiPMs drives unit cost down
- Mandates additional collectors (eg lightguides)
- Collector requires optimization

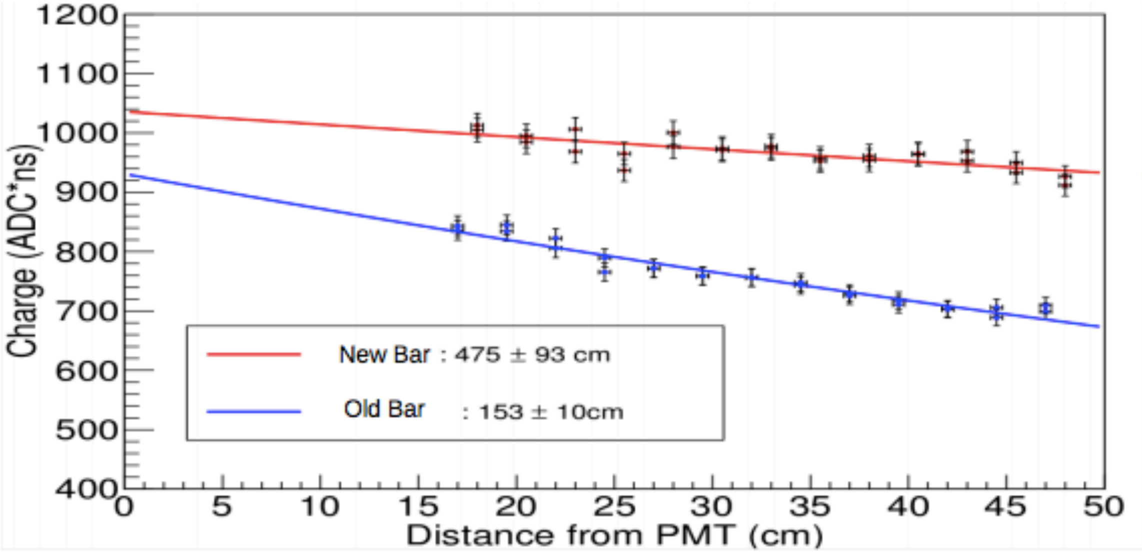
Improved TPB Coating

Jarrett Moon – LIDINE2015 talk

- Increase TPB/acrylic ratio

0.5 g TPB	→	0.1 g TPB
50 mL toluene	→	50 mL toluene
10 mL ethanol	→	12 mL ethanol
1 g acrylic	→	0.1 g acrylic

- Initial test done in air, and showed *drastic* improvement

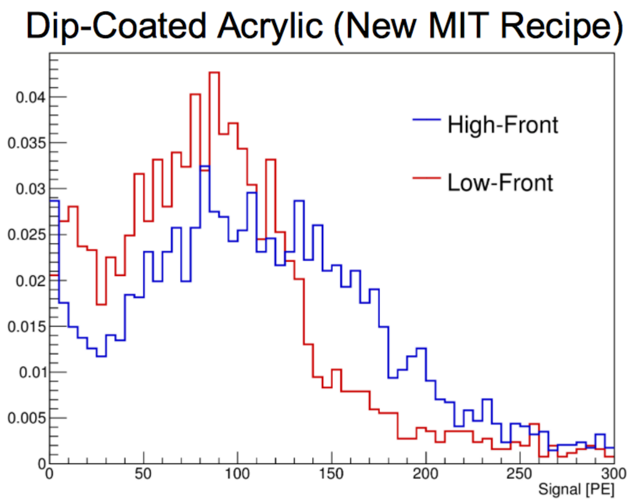


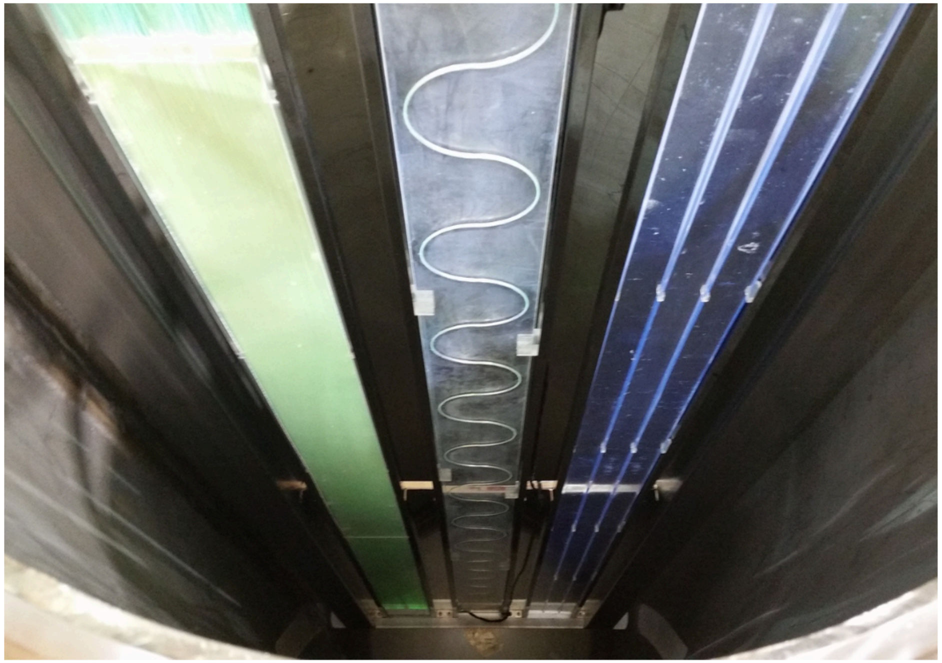
But for such a seemingly drastic improvement, the proof is in the pudding

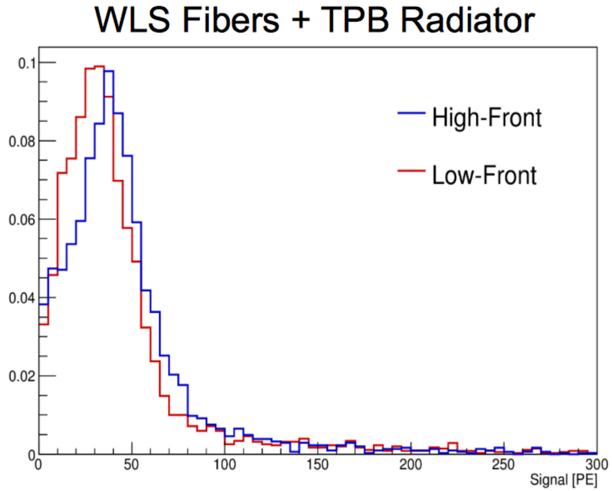
(pudding = LAr)

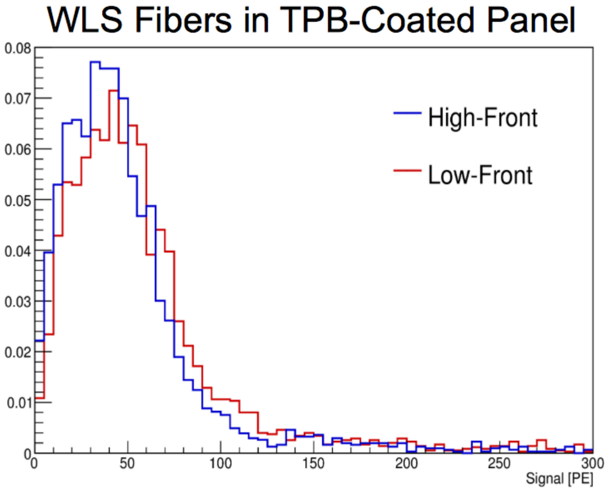
Competing light guide designs

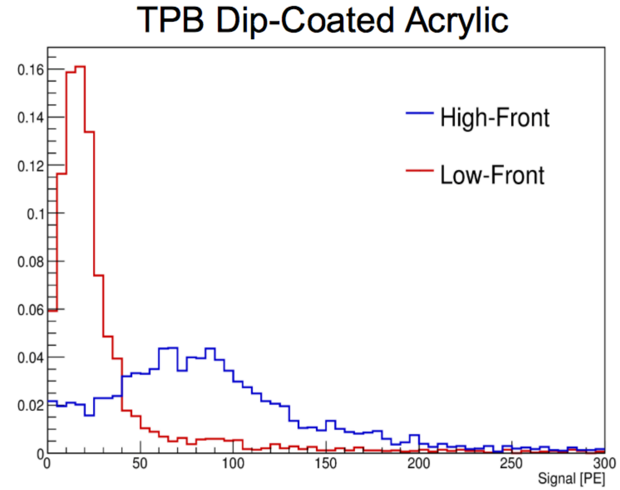
Denver Whittington – LIDINE2015 talk









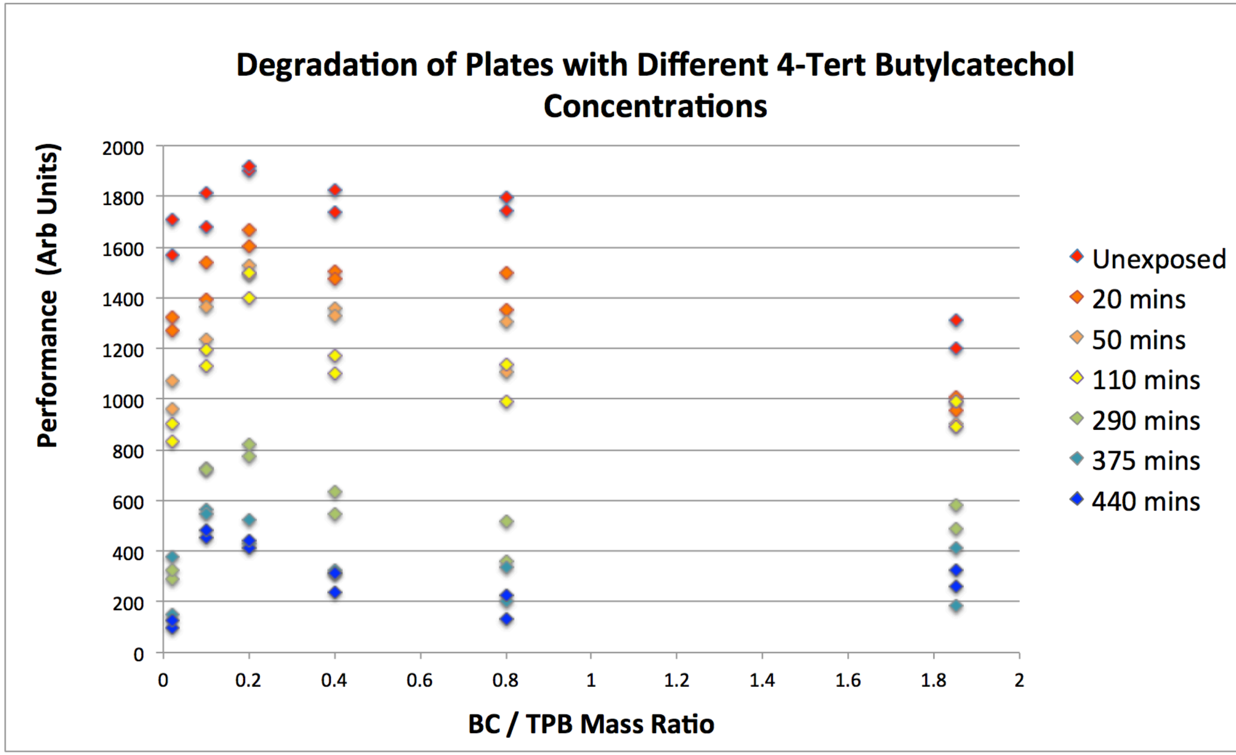


Improvement by chemical stabilization

Improved initial performance and stabilization can be achieved with radical mediators

Interpretation: Partial TPB->BP decay in solution during coating preparation

More exploration of stabilizers could yield brighter TPB-PS coatings



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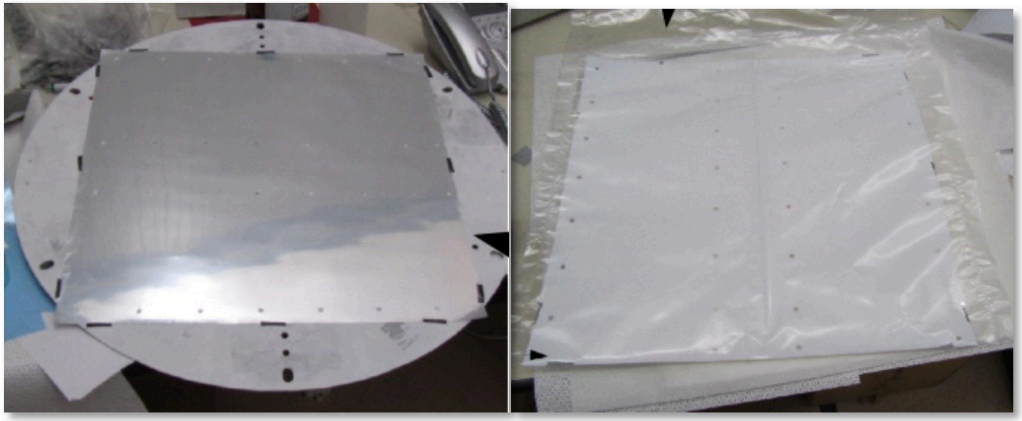
B J P Jones *et al* 2013 *JINST* **8** P01013 doi:10.1088/1748-0221/8/01/P01013

Photodegradation mechanisms of tetraphenyl butadiene coatings for liquid argon detectors

B J P Jones[a], J K VanGemert[b], J M Conrad[a] and A Pla-Dalmau[b]

LArIAT-style foils

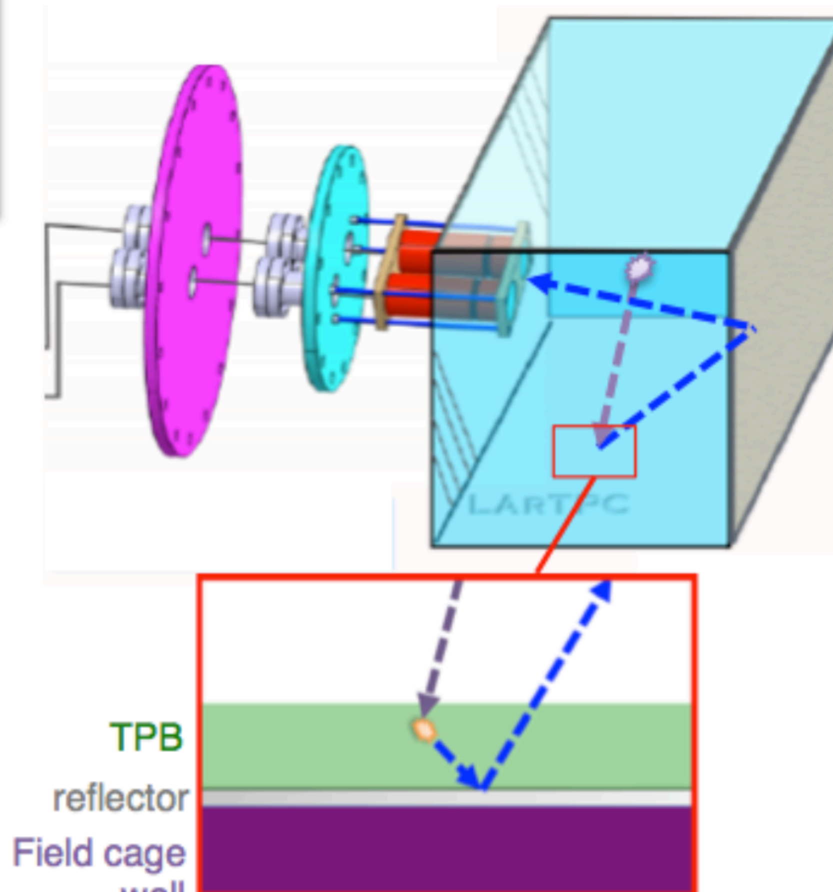
Will Foreman – LIDINE 2015 talk



Reflector foil before/after TPB evaporation

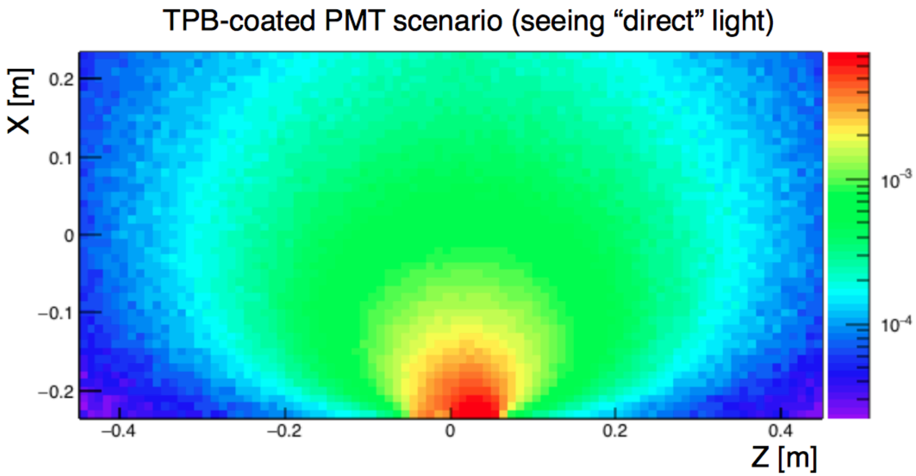
Test-mount of mock foil masks.

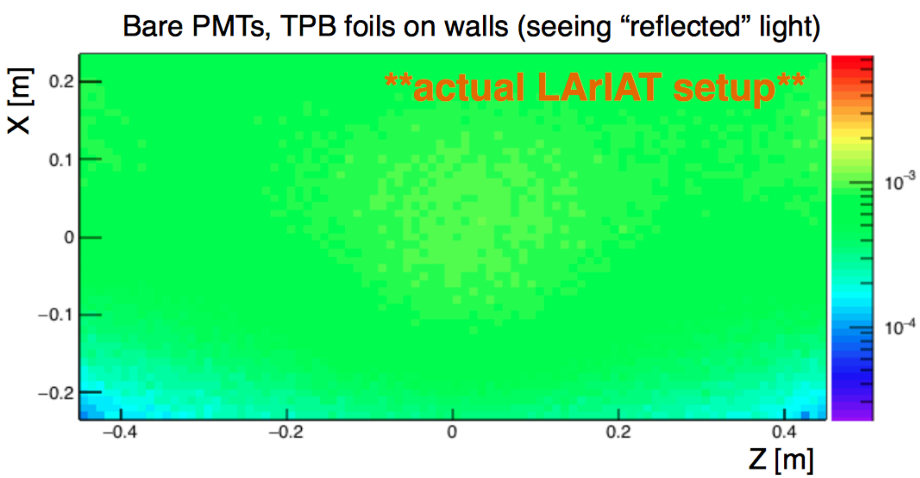
Reflector-based solution (LArIAT)



Advantages of foils

- Detector is small, so cosmic background not problematic.
- LArIAT collection all light at one spot – foils homogenize detector response (good!)
- Detector goal is to study charge and light emission – so get lots of it (good!)
- On the flipside, very little spatial information in the reflected light.

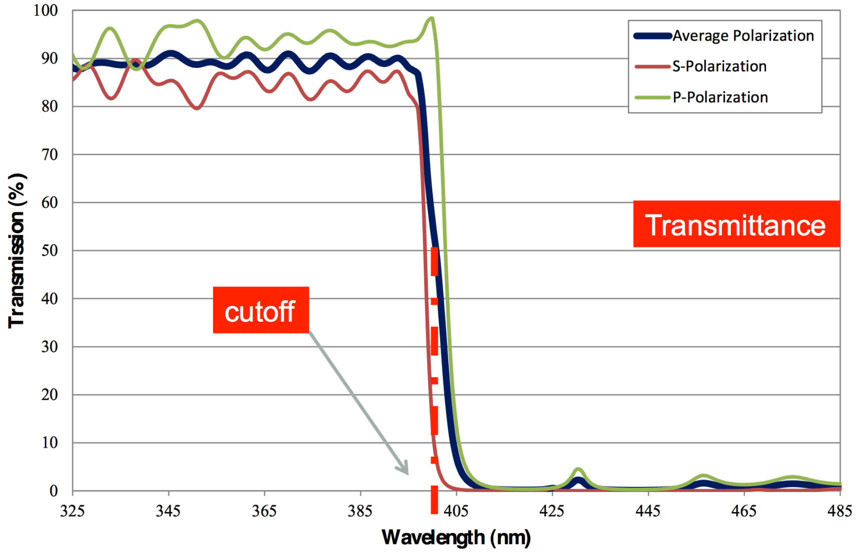


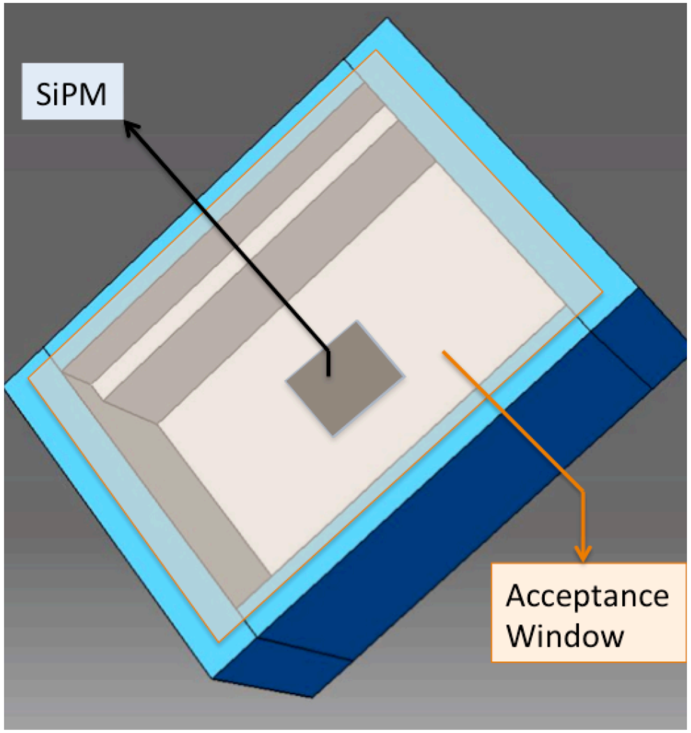


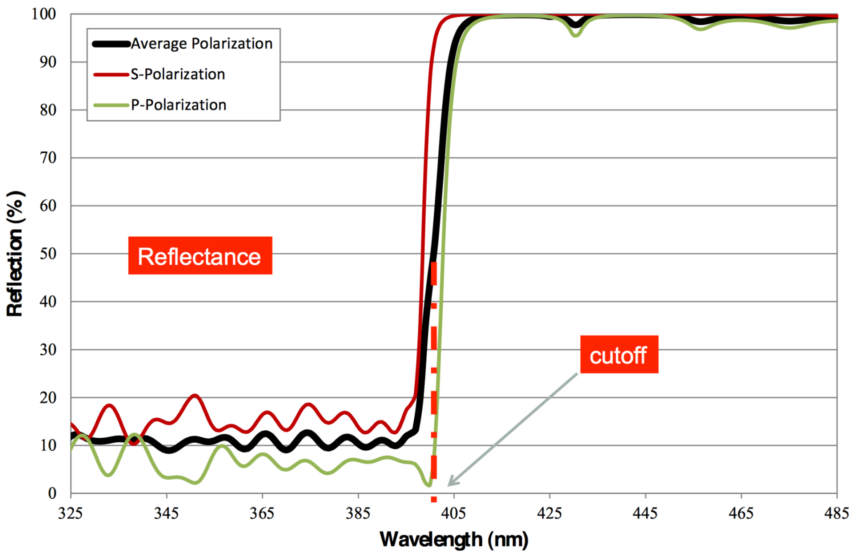
Will Foreman – LIDINE 2015 talk

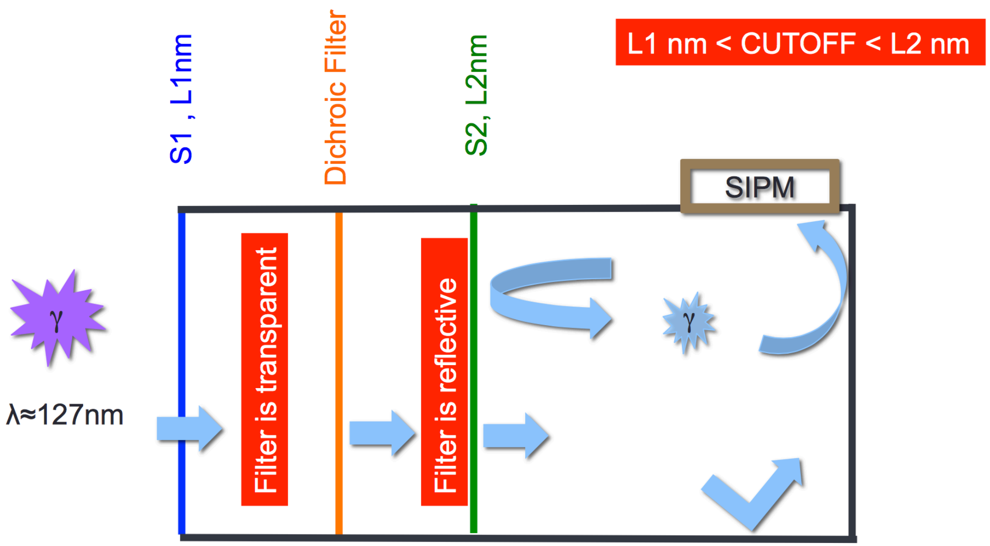
The ARAPUCA

Ettore Segretto – LIDINE 2015 talk



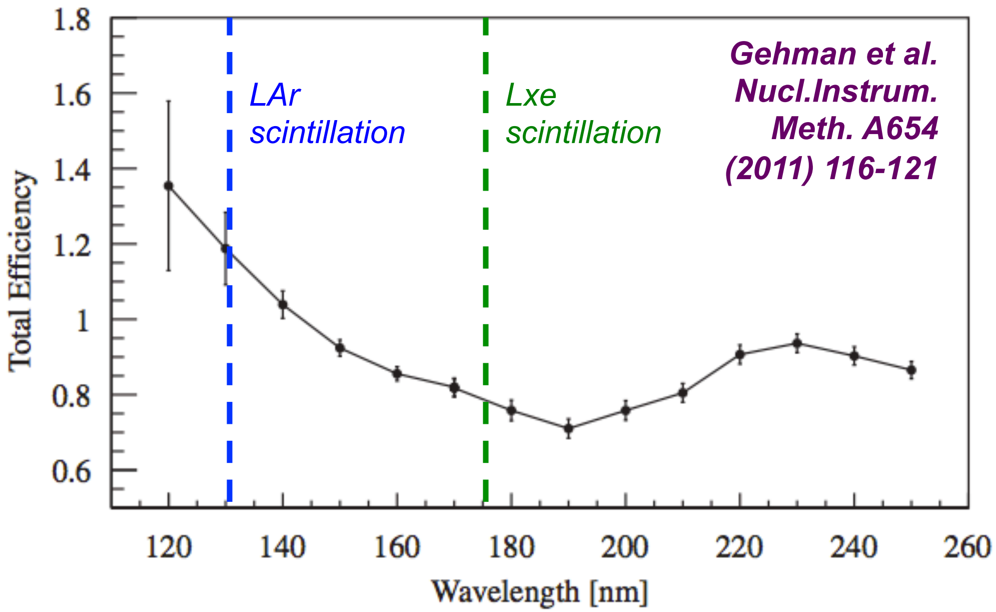


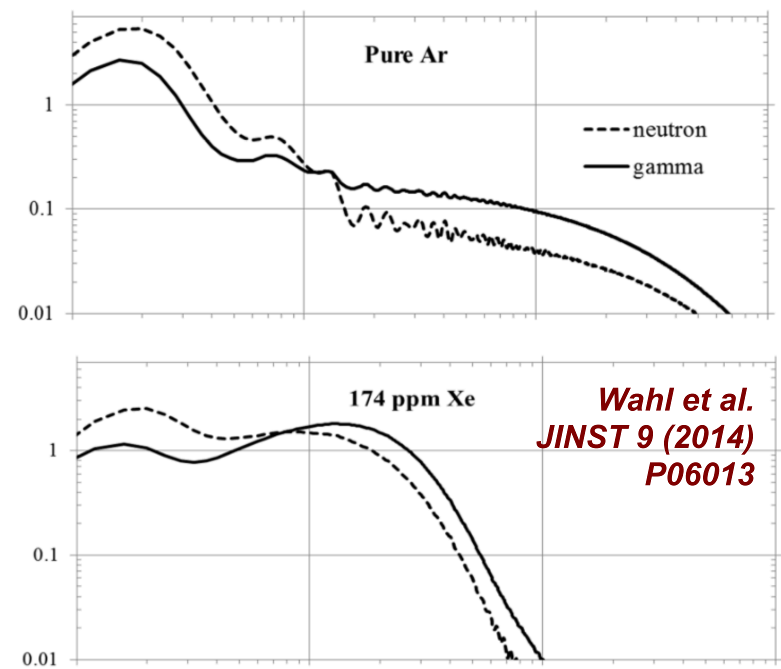




Xe Doping

- Addition of xenon can produce excitation transfer which moves light to earlier times.
- **Common myth** : “TPB is brighter at LXe wavelengths” – not true!
- But bringing late light to earlier times after the pulse makes it more easily collectable, and more useful.
- ~100 ppm required → multiple tons for DUNE. Not a cheap proposal.





Summary

- Liquid argon TPCs are an important part of the US neutrino physics program
- Light collection systems are important for background rejection, drift-position measurement
- Significant R&D was required to realize present-generation experiments
- R&D for next-generation experiments should focus (IMO) on spatial specificity for geometrical tagging
- This can be achieved with more channels per $ and more light per channel
- There are old ideas, new ideas, and ideas yet-to-be-had that can make this happen.